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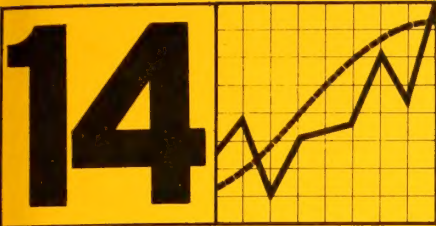












# Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America



## ECONOMIC CONSIDERATIONS





## ABSTRACT

Although many effects of forest and rangeland management on anadromous fisheries are difficult to measure, economic methods for the evaluation of costs and benefits can be helpful. Such methods can be used to address questions of equity as well as efficiency. Evaluations of equity can show who bears the costs and who captures the benefits of management actions, but cannot judge the goodness of any particular allocation of cost and benefits. The efficiency of the management and commercial harvest of anadromous fish is determined to a large extent by the regulation of fish harvest. Although the gross market value of harvested fish is large, the net economic value of the fishery may be very small where the thrust of regulation is to limit harvest by forced inefficiencies in fishing. With the institution of limited entry in commercial salmon fisheries, opportunity increases for generating net economic value from increased fish runs. Also, potential economic benefits to consumers and anglers may accrue from maintaining or enhancing anadromous fish populations. Where these benefits exceed costs of habitat protection, a valid economic basis exists for incorporating fish-habitat protection in forest and rangeland management practices.

KEYWORDS: Fish habitat, anadromous fish, cost/benefit evaluation, management (forest), range management.

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INFLUENCE OF FOREST  
AND RANGELAND MANAGEMENT  
ON ANADROMOUS FISH HABITAT  
IN WESTERN NORTH AMERICA

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14. Economic Considerations

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## PREFACE

This is one of a series of publications on the influence of forest and rangeland management on anadromous fish habitat in western North America. This paper addresses the physical, political, and economic characteristics of western anadromous fisheries, and discusses biological and economic concepts for evaluating and managing fishery resources. Our intent is to provide managers and users of forests and rangelands with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we will summarize published and unpublished reports and data as well as the observations of scientists and resource managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.
2. "Impacts of natural events," by Douglas N. Swanston.
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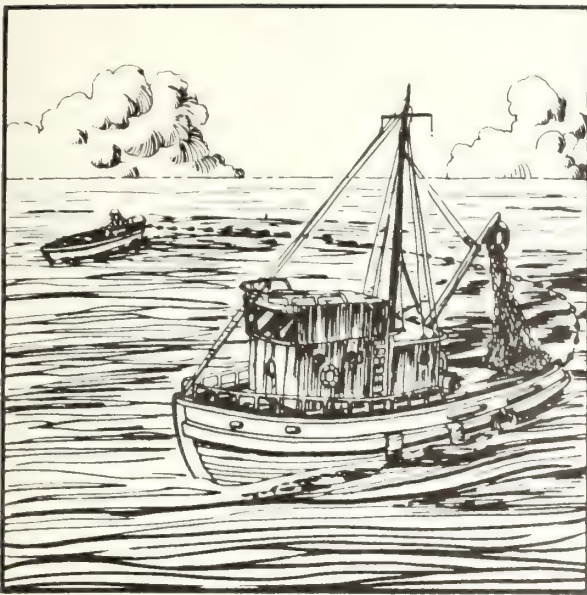
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## COMMON AND SCIENTIFIC NAMES OF FISHES MENTIONED IN TEXT AND TABLES<sup>1/</sup>

Common name	Scientific name
Pink salmon	<u>Oncorhynchus</u> <u>gorbuscha</u> (Walbaum)
Chum salmon	<u>Oncorhynchus</u> <u>keta</u> (Walbaum)
Coho salmon	<u>Oncorhynchus</u> <u>kisutch</u> (Walbaum)
Sockeye salmon (kokanee)	<u>Oncorhynchus</u> <u>nerka</u> (Walbaum)
Chinook salmon	<u>Oncorhynchus</u> <u>tshawytscha</u> (Walbaum)
Cutthroat trout	<u>Salmo</u> <u>clarki</u> Richardson
Rainbow (steelhead) trout	<u>Salmo</u> <u>gairdneri</u> Richardson
Dolly Varden	<u>Salvelinus</u> <u>malma</u> (Walbaum)

<sup>1/</sup>From "A List of Common and Scientific Names of Fishes from the United States and Canada," American Fisheries Society Special Publication 12, Fourth Edition, 1980, 174 p.





## INTRODUCTION

Economic considerations in the management of anadromous fish habitat fall into two major categories: economic efficiency and economic equity. Assessing economic efficiency in resource management focuses on the costs and benefits obtained from alternative patterns of use. "Efficiency" implies maximizing overall benefits, minus costs. Techniques of cost-benefit analysis developed over the past few decades allow us to estimate monetary values of a wide range of resource-based activities. Commercial fishing, mineral extraction, logging, and livestock grazing are commodities that have a clear economic value. Economists are also interested in estimating values for noncommodity activities, such as recreational fishing, camping and back-packing, and preservation of natural sites. Because of both data and conceptual limitations, cost-benefit analysis does not always accurately estimate net economic benefits. Nevertheless, cost-benefit analysis is the best means of assessing the overall economic efficiency of alternative resource-management policies.

Economic efficiency, broadly defined, is the essence of the Water Resources Council (WRC) (1982) Guidelines, which require agencies to develop as one alternative a plan that reasonably "... maximizes net national economic development benefits . . . ." The guidelines further state that the recommended plan "... is to be the alternative with the greatest net economic benefit, unless the Secretary of a department or head of an independent agency grants an exception to this rule" (Water Resources Council 1982). Economic efficiency is also the essence of the USDA National Forest System land- and resource-management planning regulation stating, "The primary goal in formulating alternatives, besides complying with NEPA procedures, is to provide an adequate basis for identifying the alternative that comes nearest to maximizing net public benefits . . ." (U.S. Department of Agriculture 1982).

Economic theory provides no clear guidance on the "equity" of management alternatives; however, some generally recognized principles help define the fairness of any distribution of benefits. For example, arbitrarily impoverishing particular groups or denying access to long-standing resource users without compensating them are actions normally considered inequitable. They are examples of what economists call redistributions of income or wealth. Economic methods can be used to anticipate and measure the probable effects of redistributions by identifying specific groups or individuals bearing significant portions of the costs or receiving significant portions of the benefits of management choices.

This paper explores the effects of forest and rangeland management on the economics of commercial and sport harvest of anadromous fish. The overall effect that forest and rangeland management has on the net benefits to producers and consumers of anadromous fish, as well as the cost incurred by resource managers and owners, is included.

# ECONOMIC DIMENSIONS OF ANADROMOUS FISHERIES IN THE PACIFIC

Commercial salmon harvests by all nations bordering the north Pacific Ocean have recently averaged over 221 million fish per year (table 1). The United States catches slightly more salmon than do Japan and the Soviet Union. Canada takes less than one-third as many fish per year as do the other three. The five major commercial species of salmon are sockeye (or red), chum (or dog), pink (or hump-back), coho (or silver), and chinook (or king). Three additional anadromous salmonids occur in western North America--steelhead and cutthroat trout, and Dolly Varden.

Salmon fisheries are classified according to geographical separation, political boundaries, fishing gear used, and motivation for fishing (recreation, subsistence, or commercial livelihood). Table 2 shows the breakdown of catches by some of the more significant divisions. Commercial purse-seine and gill-net fishing occur in protected waters such as Puget Sound, the Columbia River, and the inside waters of Southeast Alaska. Commercial trolling dominates the ocean fishery in California, Oregon, and Washington. Trolling is significant in southeastern Alaska as well. Historically, some species of salmon (especially chinook, coho, and sockeye) were caught primarily by traps, "fish wheels," and dip nets during spawning runs (Netboy 1980). These fishing techniques were more effective and less expensive than ocean fishing, but they are now generally prohibited.

Table 1--Average annual north Pacific commercial salmon catches, 1976-80

	Sockeye	Chum	Pink	Coho	Chinook	Total
----- Thousands of fish -----						
U.S.S.R.	910	4,744	55,730	1,116	171	62,671
Japan	3,787	29,838	24,885	2,228	401	61,139
Canada	5,534	1,958	8,620	3,309	1,458	20,879
United States:	22,460	8,058	38,459	5,495	2,194	76,676
Alaska	21,097	7,340	37,106	2,478	676	68,697
Washington	1,363	712	1,337	1,883	633	5,928
Oregon	0	6	25	896	333	1,260
California	0	0	1	238	552	791
Total	32,691	44,598	127,704	12,148	4,225	221,365

Sources: Fredin (1980), Food and Agricultural Organization (1981).

Table 2--Annual average catches by United States user groups, 1975-79

	Commercial salmon				Recreational		
State	Purse seine	Gill net	Troll	Other gear	Salmon	Steelhead	Subsistence
----- Thousands of fish -----							
Alaska	33,487	23,067	1,332	625	329	3	67
Washington	2,388	1,738	1,258	885	1,314	105	--
Oregon	--	--	1,110	--	425	155	--
California	--	--	840	--	137	NA	--
Idaho	--	--	--	--	3	6	--
Total	35,675	25,034	4,540	1,514	2,208	270	90

-- = These fisheries do not exist in these States.

NA = not available.

Sources: U.S. Department of Commerce, National Marine Fisheries Service (1976, 1977, 1981); International North Pacific Fisheries Commission (1982).

Commercial salmon fisheries consist of many independent operations with no more than a few crew members (Petty 1979). Many trollers and gill-netters are operated by only one or two persons. Nevertheless, about 33,000 workers fish commercially at least part time in United States salmon fisheries, using 20,000 vessels (table 3). At least 727 party-boat or charter-boat operators derive a substantial portion of their business from salmon anglers. Most salmon vessels fish other marine species as well. In 1976, for example, 8,169 of the 12,558 vessels reported landing salmon in Washington, Oregon, or California also sold some groundfish, crab, or albacore.<sup>1</sup> Many are

<sup>1</sup>/Huppert, D.D.; Thompson, C.; Edwards, B. Annual summary files from the 1974 thru 1976 coastwide summary data base: contents and summary statistics. Unpublished Admin. Rep. LJ-82-29. La Jolla, CA: U.S. Department of Commerce, National Marine Fisheries Service, Southwest Fisheries Center; 1982. 46 p.

fully employed in commercial fishing for only a portion of the year, however. In comparison, the average monthly employment in logging in Oregon, Washington, and California was about 28,000 in 1978. Logging is also seasonal; the number of people employed in logging at some time during the year is substantially more than the average monthly figure. The average monthly employment in the timber industries of these three States, including logging, sawmills, veneer and plywood mills, and pulp and paper mills, was about 129,000 in 1978.

Table 3--Estimated number of fishing units and employment in salmon fisheries

State	Commercial fishing fleet				
	Vessels by gear type used				
	Trawl	Gill net	Purse seine	Crew	Party charter boats
	Number				
Alaska	872	3,500	1,244	11,931	--
Washington	2,601	3,169	396	7,889	44
Oregon	3,259	210	--	5,251	11
California	4,150	--	--	8,316	6
Total	10,890	7,387	1,640	33,089	71

-- = These fisheries do not exist in these States.

Sources: Pacific Fishery Management Council, "Third-Draft Framework Plan for Managing Ocean Salmon Fisheries Off Washington, Oregon, and California," Portland, OR, 1983, 133 p.; "Proposed Plan for Managing the 1983 Ocean Salmon Fisheries Off of Washington, Oregon, and California," Portland, OR, 1983; Alaska Commercial Fisheries Entry Commission (1982); U.S. Department of Commerce, National Marine Fisheries Service (1981).

In recent years, commercial salmon fishing has grossed around \$300 million to \$400 million (table 4). The finished products (mostly canned pack, cured, and fresh or frozen fillets and steaks) have a market value of around \$1 billion wholesale (table 5). Of this \$1 billion in wholesale value, about \$20 million to \$40 million is produced in Oregon, Washington, and California. In comparison, the estimated wholesale value of timber products produced in Oregon and Washington was about \$8.5 billion in 1978.

Table 4--U.S. commercial landings of Pacific salmon by species and year: ex-vessel values, 1950-82

Year(s)	Landings					Total	Average
	Sockeye	Pink	Chum	Coho	Chinook		
	Millions of pounds						
1950-54	89.6	101.9	73.8	38.5	39.2	343.0	4.1
1955-59	68.1	93.9	51.6	24.4	32.9	270.9	41.7
1960-64	71.5	124.7	52.6	26.2	26.4	301.4	51.6
1965-69	90.3	111.0	41.7	34.9	27.3	305.2	7.1
1970-74	82.4	69.0	52.4	36.0	29.1	269.7	97.2
1975-79	103.0	143.5	48.0	33.6	32.3	357.4	14.1
1980	207.6	253.5	84.9	39.1	28.5	613.6	14.1
1981	226.2	257.1	98.9	35.2	31.1	648.5	438.2
1982	200.2	221.5	92.0	59.2	34.6	607.5	392.0

Sources: U.S. Department of Commerce, National Marine Fisheries Service (1973); U.S. Department of Commerce, National Marine Fisheries Service (1971-82).

The salmon fishery--along with tuna and shrimp fisheries--is one of the three most valuable marine commercial fisheries in the United States, based on gross market value. Much of the increase in salmon market values since the early 1950's was caused by increased prices. The average ex-vessel price rose from \$0.126/lb in 1950 to 1954, to \$0.669/lb in 1975 to 1980. In recent years, huge runs of Alaska sockeye and pink salmon have caused a moderate drop in ex-vessel prices.

Recreational fishing expanded during the past two decades to become a major user of the salmon resource in certain areas--particularly in Puget Sound, the southern part of the Washington coast and Columbia River mouth, and the northern Oregon coast. According to State records, annual sport salmon harvests nearly doubled from an average of 546,000 fish per year in 1950 to 1954, to 1,018,000 fish in 1976 to 1980. Although the sport harvest does not rival the commercial harvest, major portions of the coho and chinook salmon catches are taken by recreational hook-and-line, and almost all of the steelhead are taken by recreational anglers.



Table 5--Quantity and value of processed fishery products from the United States' north Pacific salmon fisheries

	1976	1977	1978	1979	1980	1981
<b>Pacific coast:</b>						
Fresh and frozen-- <sup>1/</sup>						
Quantity (thousand of pounds)	4,129	3,153	4,111	3,042	1,582	2,826
Value (thousands of dollars)	8,281	7,015	9,885	6,282	4,263	7,863
Canned-- <sup>2/</sup>						
Quantity (thousands of cases)	156	243	16	53	18	167
Value (thousands of dollars)	17,121	25,824	1,798	5,825	4,169	17,336
Cured-- <sup>3/</sup>						
Quantity (thousands of pounds)	5,055	4,504	5,602	3,677	3,465	4,046
Value (thousands of dollars)	14,523	16,825	21,817	14,298	12,737	16,119
<b>Alaska:</b>						
Frozen-- <sup>1/</sup>						
Quantity (thousands of pounds)	50,578	76,674	121,419	149,211	195,404	283,265
Value (thousands of dollars)	101,438	170,589	291,955	308,134	526,553	788,150
Canned-- <sup>2/</sup>						
Quantity (thousands of cases)	2,512	2,651	3,409	3,109	4,175	4,445
Value (thousands of dollars)	190,745	180,753	242,260	286,422	400,060	440,911
Cured-- <sup>3/</sup>						
Quantity (thousands of pounds)	3,783	NA	NA	NA	NA	NA
Value (thousands of dollars) <sup>4/</sup>	11,880	NA	NA	NA	NA	NA
Total Value	343,988	401,006	567,715	620,961	947,782	1,270,379

NA = not available

<sup>1/</sup>Includes steaks and fillets.

<sup>2/</sup>Standardized to 48 1-lb cans.

<sup>3/</sup>Includes smoked fish, caviar, bait eggs, and salted fish.

<sup>4/</sup>Actual values not available. These values estimated using average price for frozen products on the Pacific coast.

Sources: U.S. Department of Commerce, National Marine Fisheries Service (1975-81); The Fishermen's News (1983).

The economic importance of recreational fishing is more difficult to measure than that of commercial fishing because of the lack of market prices. Special fishing surveys in Washington, California, and Oregon estimate total recreational expenditures to be around \$186 million per year for salmon and steelhead fishing trips (table 6). This figure includes travel, on-site, and gear expenditures. Another measure of economic value is the net amount the recreationists would be willing to pay for fishing over and above costs.

This net economic value for salmon angling is estimated to be about \$83 million in Washington, Oregon, and California (table 6). Equivalent values are not available for Alaska because the necessary studies have not been performed.

Table 6--Estimated economic measures for recreational salmon and steelhead fishing

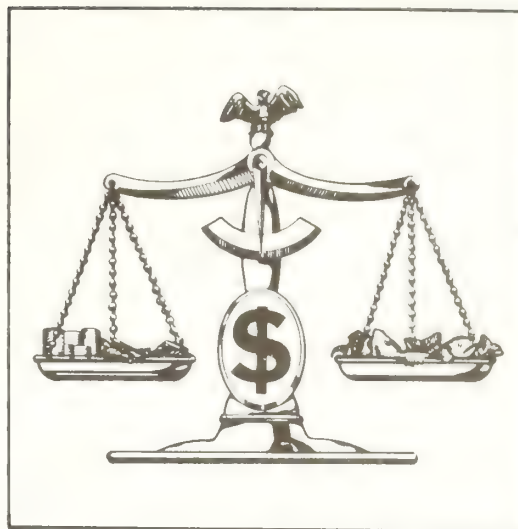
	Expenditures	Net value
- - - Millions of dollars - - -		
Washington	126.3	42.5
Oregon	53.2	31.5
California	6.3	9.0

Sources and procedures:

1. Washington and Oregon expenditures from Sorhus and others (1981).
2. California expenditures estimated from 1976-80 average annual ocean salmon angler-days (179,820) and average expenditure per day for San Francisco area partyboat salmon anglers (\$55.50) from 1979 National Marine Fisheries Service survey reported by Center for Natural Areas ("Survey of Partyboat Passengers to Summarize and Analyze Recreational Demand for Partyboat Fishing in California," Southwest Fisheries Center Administrative Report No. LJ-80-14C, La Jolla, CA, 1980, 75 p.).
3. Net-value estimates for Washington and Oregon are from Brown and others (1980). California net value is estimated by multiplying number of trips by \$50, about midway between the estimated day-values for Oregon and Washington ocean salmon-fishing trips.

Subsistence fishing is important for residents of Alaska and for Native Americans in certain areas of Washington, the Columbia River, and the Klamath River. Native Americans constitute a growing portion of those fishing commercially. In Washington and Columbia River fisheries, they are increasingly using their historical fishing rights, which were established in Federal Courts. These rights allocate harvestable portions of the fish stocks that return to the "usual and accustomed" fishing places as specified by treaty. During 1976 to 1981, harvests by Native Americans increased from about 1 million to 3 million fish per year in Washington and the Columbia River. Because total annual harvests (treaty and non-treaty commercial plus recreational) remained between seven and eight million fish, treaty fisheries have taken an increasing share of the harvest in the region.

The north Pacific salmon and steelhead fisheries are extremely widespread, diverse, and economically significant. These fisheries provide employment to thousands fishing commercially and also shoreside workers. Often the fishery is one of the few livelihoods available in isolated coastal communities. Large numbers of salmon contribute to the subsistence of many people. Among recreational anglers in Alaska and the Pacific Northwest, salmon and steelhead fishing are extremely popular. Anadromous fish are thus a resource worthy of substantial consideration in resource-management decisions.



## CONCEPTS OF ECONOMIC VALUATION FOR FISHERIES

To understand and properly use estimates of economic value, several related concepts must be distinguished. An economic value given to a particular resource or industry can be divided into those values accruing to consumers, producers, taxpayers, and resource owners. The economic value may be positive to one group, but negative to another. For any given target group, the value may be calculated as an "all-or-nothing" value or as a "marginal" value. An all-or-nothing value is the value of having resources or commodities, rather than not having them; the marginal value is the value of a small change in the quantity of the resource or commodity. Estimates of value can apply to one or more potential uses for a resource; for example, commodity value pertains to the increase in value when basic materials or resources are made into consumable goods, and amenity values often come from natural environments and in situ resources.

In practice, the economic value of some commodity or activity is measured as the dollar amount that consumers or business firms are willing to pay for the commodity. This "willingness to pay" can be expressed as an all-or-nothing value, representing the total amount consumers would pay to avoid going without the existing amount of the commodity. The marginal value--an increase or decrease in willingness to pay associated with a small increment or decrement to existing quantities supplied--is often more useful to know. Most forest- and rangeland-management decisions are concerned with marginal effects on commodity markets.

## COMMODITY VALUES

Values of commodities are related to the market-demand curve (fig. 1). If consumers allocate their expenditures among commodities to maximize their well-being, they will purchase more of virtually any product when the price is low, and less when the price is high. This theory explains why the demand curve depicted in figure 1 slopes downward to the right. For any given consumption rate, there is a maximum price consumers will pay for an additional unit. This price is a useful measure of the marginal value of the product to consumers. Multiplying the price times the quantity demanded yields the gross market value.

Gross market value of harvests is commonly available for whole fish at dockside, processed fish at wholesale, and retail fish in final goods markets. Similar values can be computed for stumpage or forage, wholesale primary wood products or beef, or for finished wood products or meat in consumer markets. Although gross market value can be a useful indicator of industry size, it is of limited use in assessing economic benefits from an industry because it represents neither the value of the total supply to consumers, nor the net economic value accruing to producers.

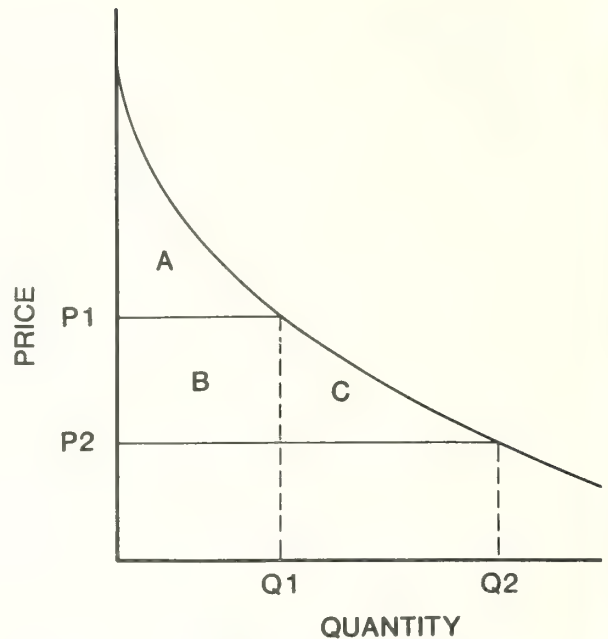


Figure 1.--Market-demand curve. If quantity increases from  $Q_1$  to  $Q_2$ , market price would fall from  $P_1$  to  $P_2$ . Total willingness to pay, for quantity  $Q_1$ , equals the area labeled A, plus the gross market value  $P_1 \times Q_1$ . Consumer surplus--the amount consumers are willing to pay above the amount they actually pay--for  $Q_1$  is equal to area A.

When large changes occur in quantity supplied, the market price and underlying marginal value to consumers will change. If quantity supplied increases from  $Q_1$  to  $Q_2$  (fig. 1), the market price would fall from  $P_1$  to  $P_2$ . Gross market value could rise or fall depending on whether the percentage change in price is less than or greater than the percentage change in quantity. Neither the change in gross market value, nor the change in quantity times the original price is a valid measure of the change in economic benefits. Consumers are better off with the lower price because they can still buy the original quantity and have money left over.



Economists use willingness to pay to measure the amount by which consumers are better off. For any given quantity consumed, the demand price represents the amount consumers are willing to pay for a marginal increase in consumption. If we value each unit--from the first one up to the actual quantity consumed--at its marginal value, the total willingness to pay would be measured by the area under the demand curve. For quantity  $Q_1$ , for example, this total would equal the area labeled A plus the gross market value  $P_1 \times Q_1$ . The consumer surplus--the additional amount consumers are willing to pay above the amount they actually pay--for quantity  $Q_1$  is equal to the area A. By similar reasoning, the increase in consumer surplus associated with an increase in quantity from  $Q_1$  to  $Q_2$ , accompanied by a price decrease from  $P_1$  to  $P_2$ , is represented by the sum of areas B and C. The change in consumer surplus is the most relevant measure of the change in benefits to consumers.

Producers, like consumers, may enjoy a surplus. The producer surplus is the excess of market value over the costs of production, where costs must include reasonable payments to labor, management, and capital, as well as payments for other raw materials. This surplus may be represented by profits earned by firms in the industry. The change in producer surplus is the most relevant measure of the change in benefits to producers.

Producers of natural-resource commodities usually draw on some resource stock such as a fish population, forest, or mineral deposit. When producers find that production of commodities from a particular resource is profitable, they should be willing to pay fees to the resource owner. In a private-enterprise economy with private-property rights established for natural resources, the fees actually paid contain two distinct components: an economic rent, and compensation for maintenance and other costs incurred by the resource owner. The rent is an economic surplus similar to a profit.

Economic rent reflects the scarcity of a fixed, productive asset, whereas profit reflects the success of firms at generating revenues in excess of operating costs. When commodity producers also own the resource, or when publicly owned resources are provided free to producers, reporting of profits versus rents is muddled; the rental value of resources may be hidden in the reported profits of producing firms. Regardless of how the rental value of a scarce resource is reported in the industry's accounts, two distinct economic surpluses are to be included as benefits to the producer side of the market--profits and rents. Consequently, the total net economic value accruing to the economy through production of natural-resource commodities consists of consumer surplus, producer profits, and resource rents.

Market prices and monetary costs recorded by business firms provide information on economic values and costs. This is especially true if prices and costs are determined in a perfectly competitive market. A competitive market is one with sufficient numbers of buyers and sellers to prevent any one of them from establishing the going price, where all buyers and sellers are free to buy or sell as much as they want at the going price, and where property rights to the commodities being sold are well defined and exclusive. Exclusive means the rights to use, to exclude others from use, and to sell a unit of the commodity are vested in its owner. Under these conditions, market prices are a good measure of the marginal value to society, and the marginal costs of producers are a good measure of the marginal cost to society.

The same conclusions apply in other markets. If labor and capital markets are perfectly competitive, the wage rates and rates of return on capital observed represent valid measures of the full social costs of using these factors of production. Where competitive markets establish rents for natural resources, the rents represent the marginal value of the resource to commodity producers. In the United States, however, many resources are not sold competitively. Some markets are dominated by large firms that dictate prices, and--more importantly--for many resource commodities (especially those associated with the public good, such as air and water quality, natural fish runs, and environmental amenities), clear private-property rights have not been established. When property rights are insufficient to define the various rights and responsibilities of all resource users, free use of or competition for the resource often results in what economists call an externality. When logging operations damage salmon spawning gravels, an external cost is imposed on the salmon-fishing industry. Similarly, when salmon fishing is competitive for a common pool of fish, each person in effect imposes an external cost on others because fish are harder and more costly to catch when the available stock is smaller. Finally, competitive market allocation of land and of associated renewable and nonrenewable resources is uncommon on public lands administered by Government agencies. When competitive markets do not function or external costs are imposed by one firm on others, private market prices do not provide an adequate basis for measuring economic value.

The market for public forage does involve a payment by the rancher to the agency, but the price is determined administratively, not by a competitive market. The actual price paid may be higher or lower than the market price that would prevail if forage were allocated through competitive bidding. The market for publicly owned timber also involves a payment based on the amount harvested. In general, the payment is based upon an oral or sealed-bid auction. In those areas with sufficient competition for timber harvesting rights, the price is reasonably close to a competitive-market price. The conditions of sale are not necessarily typical of what would normally be found in an open and competitive market, however.

Because salmon fisheries are common property, administered through public agencies, no fees are paid to private owners. Traditionally, the responsible agencies charge no direct fees for capture of fish. States do charge annual license fees, and sometimes they collect a flat-rate poundage fee for fish landed. Thus, economic value of the anadromous fish resource cannot be calculated based on fees paid, but must be estimated, based on potential or actual net revenues. The potential rent from a fish stock can be roughly calculated as the ex-vessel value of harvested fish minus the minimum necessary harvesting costs. The quantity of harvest used in this calculation would be based on knowledge of the potential yield of the fish population, and the cost estimate would depend on knowledge of the best capture technology and associated costs. Expecting actual fisheries to generate a net economic value equal to this potential rent is unrealistic because of the common property status of the fish population and traditional fishery-management methods--which seek to conserve the fish stocks but do not encourage economically efficient harvesting. Actual net revenues from commercial fisheries are generally a small (if not vanishing) proportion of potential rent.



## RECREATIONAL VALUES

Although recreational fishing values are expressed as value per fishing day or fishing trip--not value per fish--the demand curve still can be used for analysis. Using figure 1 as reference, suppose that price is replaced by cost of getting to a particular site and fishing there. Quantity is the number of times per season or year that the angler goes fishing. When costs per trip are lower, anglers go fishing more often; thus, the demand curve slopes down to the right. The main problem is that recreational fishing is not sold in private markets. Estimation of the recreational demand curve requires indirect information, such as expenditures, fishing participation patterns, and possibly other socioeconomic data on anglers. Furthermore, it requires application of complex sets of assumptions and models. For full explanations of the alternative procedures available, see Desvousges and others (1983), Dwyer and others (1977), Freeman (1979), or Huppert (1983).

Once a demand curve for recreational fishing is estimated, a consumer surplus value can be given to fishing. As in commercial fishery evaluation, a net economic value for a change in total quantity consists of the marginal value of the increment to consumers, minus the marginal cost of producing the increment. Recreational commodities differ from commercial ones, however, in that commercial goods are generally distributed widely, making market prices nearly uniform, except for differences in transportation costs. Recreation, however, cannot be shipped to consumers; consumers have to go to the fishing site and produce their own recreation. Consequently, the costs of recreational fishing will be higher for anglers more distant from fishing sites. The value of recreational fishing to an angler will be lower for more distant sites, because the costs to use them are higher.

Fishing values are often expressed as an average per fishing trip or fishing day. If used carefully, these unit-day values are good approximations of the value of recreational fishing. Table 7 is a summary of salmon- and steelhead-fishing value estimates compiled by Meyer (1982). The wide range of values is partly from variations in research methodologies and partly from variations in the quality of recreational fishing being studied. Some of the factors that make salmon and steelhead fishing a heterogeneous activity are accessibility, scenery, congestion, and catch rate at different fishing sites.

To evaluate fishery management properly, the marginal value of salmon added by management and enhancement should be known. Unfortunately, estimates of fishing-day values are not easily translated into estimated values of fish caught because the satisfaction of anglers depends on various attributes of the fishing trip. Relaxation, the challenge of dealing with natural hazards, the excitement of the hunt, communion with nature, and the provision of food are all valued by recreational anglers. The prevailing recreational catch rate represents just one quality variable. Greater catch per fishing day would mean higher quality fishing. Similarly, more tranquil and natural surroundings would represent an improvement in recreational quality to many anglers. Recent advances in assigning recreational values have made value estimates for increased catch rate more accurate.

Interactions between fishing and the fish population need to be examined in any comprehensive assessment of recreational fishing. Because salmon are available to recreational anglers as common property, any increase in catch rate caused by stock enhancement will attract additional fishing effort. This would shift the demand curve to the right in figure 1. More fishing, however, will cause some reduction in fish population, which will in the long run result in a lower catch rate than originally expected.



Table 7--Estimates of Pacific Northwest salmon and steelhead fishing values based on sport-fishing demand

Author	Recreational product	Year data collected	Estimated value per day	Value in 1980 dollars
			Dollars	
Brown, Singh, and Castle	Oregon salmon and steelhead	1962	13.70	39.02
Gordon	Idaho salmon	1968	8.00	19.81
	Idaho steelhead	1968	15.00	37.14
Brown, Charbonneau, and Hay	U.S. fishing (nonriver)	1975	22.00	35.20
	River salmon and steelhead	1975	51.00	81.60
Tuttle, Richards, and Wahle	Columbia River salmon and steelhead	1975	28.00	44.60
Brown, Sorhus, and Gibbs	Pacific Northwest salmon and steelhead	1977	45.00	63.94
Crutchfield and Schelle	Washington ocean salmon	1978	18.19	24.01

Source: Meyer (1982).

In specific circumstances, fishing-day values may be used in estimating the value of improved anadromous fish stocks. For example, recreational and commercial fishing seasons for coho salmon off the coasts of Oregon and Washington have been strictly limited in recent years to achieve desired spawning escapement. An increase in fish-run size would result in increased season length. If lengthened seasons would create additional fishing days with uniform quality, the increased value of recreation could be estimated by the product of average fishing-day value and the increment in number of days fished.



## MANAGEMENT OF ANADROMOUS FISHERIES

A proper evaluation of how forest and rangeland management affects anadromous fish stocks requires estimates of economic and other benefits originating from the fisheries, and estimated costs of the forest and range industries, and of the Government agencies responsible for the management. Economic performance of salmon fisheries, however, largely depends on the management procedures of the responsible agencies.

## BIOLOGICAL CHARACTERISTICS AND OBJECTIVES

Each salmon population spawning in a specific river or stream is treated as a separate stock. Fish populations are sometimes further subdivided according to the spawning season (for example, Columbia River "fall" chinook salmon). The sustainable yield of each stock depends on such factors as extent and quality of spawning gravel, and extent and quality of rearing habitat (including streamflow, cover, dissolved nutrients, and food supply). Additional factors include mortality during upstream and downstream migrations, and ocean survival. Because fishery managers control the quantity and timing of harvests only during the ocean-feeding stage and during the spawning migration of the fish, population models developed for fishery management assume a given size and quality of freshwater habitat.

One such model, a "spawner-recruit" curve (fig. 2), pertains to a group of coho salmon stocks spawning in Oregon coastal streams (Oregon Department of Fish and Wildlife 1982); however, curves for other species and stocks are similar. On the horizontal axis is an estimate of adult coho salmon reaching spawning sites in Oregon streams. Spawning stock size is plotted versus number of adult fish recruited to the fishery 3 years later (the typical time between generations). The fitted curve predicts the run size resulting from any given spawning stock, and the diagonal line is the replacement line. If the recruitment of spawning stock falls above the 45-degree line, the progeny more than replaces the spawning stock. The excess of recruitment over spawning-stock size can be harvested without causing a reduction in original stock size.

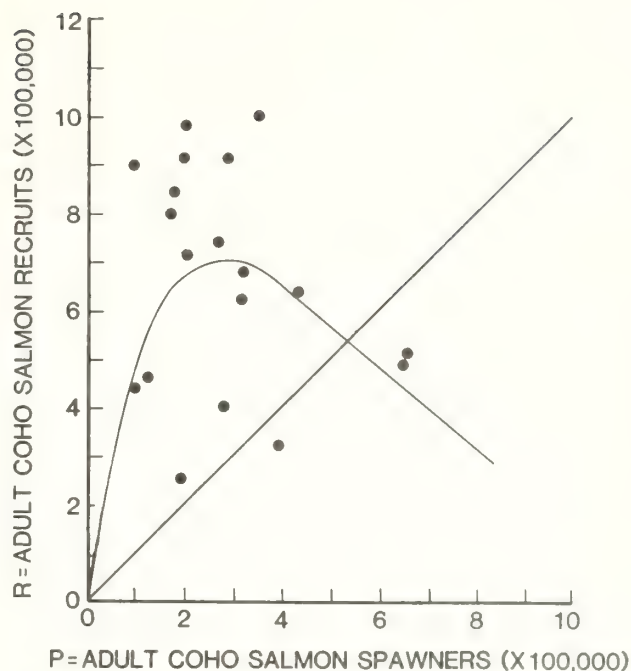


Figure 2.--Spawner-recruit curve for Oregon coastal coho salmon (adapted from Oregon Department of Fish and Wildlife 1982).

Maximum recruitment is achieved at some spawning-stock size intermediate between zero and the maximum observed (fig. 2). One biological basis for fishery management is maintenance of the spawning population to achieve maximum recruitment. Because spawning fish have survived the ocean-feeding migration and escaped the fishery to return to spawning sites, spawning-stock size and escapement are often used interchangeably. The great variability of the run sizes about their expected values is caused both by natural fluctuations in reproduction and survival of fish, and by errors in measuring the numbers of spawners and recruits. Because of the inherent variability, maintaining a maximum run size is impossible. Even if the escapement is successfully maintained to achieve the maximum run-size every year, the annual harvest would fluctuate widely.

Achievement of escapement objectives is complicated by the tendency of many salmon stocks to mix in the ocean. Variations in timing and location of oceanic migrations make it difficult to predict what proportions of each stock will be caught in a particular area. Consequently, some less-productive stocks tend to be overfished and some highly productive stocks may be underfished by a mixed-stock fishery. This problem is particularly evident when hatchery stocks mingle with natural-spawning stocks, and are then jointly harvested. Because hatchery stocks tend to have high upstream-migration survival and very high smolt production per spawner, they can sustain a higher exploitation than naturally spawning salmon stocks.

## ECONOMIC CHARACTERISTICS AND MANAGEMENT OBJECTIVES

Because of the common-property status of anadromous fish populations, competitive fishing by commercial fleets in the face of high prices would rapidly deplete stocks and severely reduce long-run economic returns. To prevent this, management agencies have historically controlled annual harvests by increasing costs of harvest rather than by reducing fleet capacity. Consequently, very little net economic return from publicly managed salmon fisheries can be expected.

The revenue and cost curves in figure 3 rely on concepts from population biology and economics. When recruitment exceeds replacement, the fishery can take the surplus without reducing subsequent run size. This surplus is equivalent to a sustainable annual yield. To construct the sustained-revenue curve, we further assume that any catch corresponds to a given fishing effort, here represented as vessel-days and measured along the horizontal axis. The total-revenue curve represents this sustained yield times market price. Total cost is equal to fishing effort times cost per unit of effort. For simplicity, both the fish price and the cost per unit effort are assumed to be independent of harvest. See Anderson (1977) for less simplistic versions of the model.

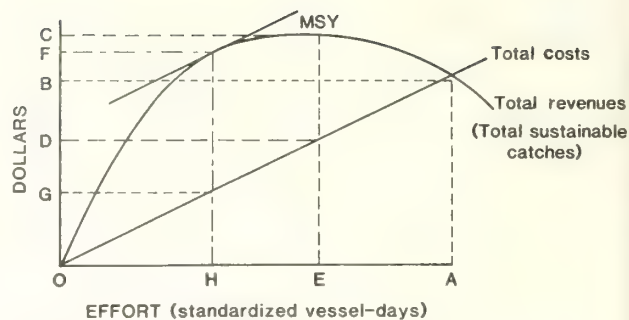


Figure 3.--Bioeconomic model of the fishery. Economic efficiency corresponds to the effort represented by point H. Economic equilibrium with open access occurs where revenues just cover all private costs of fishing, with effort at point A and revenue at point B. Because point A is to the right of the maximum sustainable yield (MSY), overharvest (in the biological sense) would be expected--but it would depend on how high the price is relative to the cost of effort.

With open access and no regulations, the competitive fishing fleet can be expected to grow until prospective profits of a new vessel are zero. Economic equilibrium occurs where revenues just cover all private costs of fishing. From a strict economic-efficiency perspective, such a resource has no value because the revenue produced is consumed in paying for the capital and labor used to harvest the fish. In fact, it would have a negative value because no surplus is left to pay for costs of managing the resource. In figure 3, this point occurs with effort at point A and revenue at point B. Because point A falls to the right of the maximum sustainable yield, this open-access fishery is expected to overharvest the stock in the usual biological sense. The extent to which this overfishing occurs in any particular case depends on how high the price is relative to the cost of effort. With a higher price or lower cost per effort, the fleet would be expected to stabilize with higher effort. With lower prices or higher costs, the fleet would stabilize with a lower effort.



Economic efficiency, which requires that the difference between revenues and costs be at a maximum, corresponds to the effort represented by point H. At this point, the slope of the revenue curve is equal to the slope of the total cost curve. At any effort greater than H, cost is increasing faster than revenue, which means that each additional unit of effort adds more to costs than to revenues. In other words, the marginal cost exceeds the marginal revenue. At any point below H, where marginal revenue is greater than marginal costs, increasing the amount of effort in the fishery makes sense. Thus, point H and the corresponding harvest are economically efficient; they give a maximum economic yield. This maximum economic yield represents the potential amount of economic rent that could be earned by a sole owner of the fish stock, if such an owner existed.

Traditional techniques of fisheries management, such as gear regulation, season closure, and quotas, all reduce catches to achieve escapement objectives; however, they tend to raise costs of fishing. To obtain a stable open-access fleet size with effort level E, cost of effort must increase until the cost curve intersects the yield curve at the MSY point. This solution is little better than the solution with open access; the total value of the resource is consumed in paying for the capital and labor used to harvest the fish, and no surplus remains to cover the cost of managing the resource. Once this point has been achieved, a price increase that raises the revenue curve further will have to be followed by more restrictions on the fishing fleet to raise costs again. Fishing costs increase through a variety of mechanisms. A reduced fishing season, for example, results in higher fixed costs per fishing day. Limiting the use of the most effective fishing gear reduces the catch per fishing day and raises costs per unit harvest. Rising salmon prices over the past two decades, coupled with

traditional management tools for achieving escapement objectives, have led to repeated increases in fleet investments and decreases in fishing opportunities for each vessel operator.

To maintain low costs while controlling the fishing fleet's harvest, fishing effort must be managed in specific ways. In recent years, management methods--such as effort control, economic rationalization, and limited entry--have been discussed and evaluated by several national and international conferences (Fisheries Research Board of Canada 1979, Rettig and Ginter 1978, Sturgess and Meany 1982). Economically efficient management requires one of two approaches: creating financial disincentives to excessive fishing effort, or establishing a private property-like right to fish. The first approach could include landings taxes or royalties, and the second could include annual individual quotas. Both represent radical departures from previous management of North American fisheries, and are not being widely accepted. These ideas are not without precedent in public-resource management, however. Royalties are collected from most mineral extraction firms on public lands, and allocation of annual forest harvests (by auction or other methods) is analogous to the individual fisherman quota.

A first step toward economic rationalization in fisheries was license limitation. Limiting licenses prevents expansion of the fishing fleet during periods of rising fish prices, and thus works toward reducing overall harvest costs. License limitation was initiated in British Columbia in 1968; Alaska began its limited entry program in 1974; and Washington, Oregon, and California began a joint, cooperative license-limitation program for salmon in 1978. The details and restrictiveness of these programs differ widely among States, and the economic consequences depend on the progress made in reducing fleet sizes and in preventing compensating increases in fishing capacity per vessel.

Much of the effectiveness of license limitation is nullified, however, because such limitation does not prevent increased investment in fishing capacity within the existing fleet size. Most license-limitation programs eventually add some form of capacity limitation to each license. In British Columbia, replacement vessels are limited to the tonnage of the previously licensed vessel. California requires replacement vessels to be declared equivalent in fishing capacity by an expert review board. These provisions make license limitation more effective, but they may not prevent operators from increasing the capacity of existing vessels. Thus, even among fisheries economists, license limitation remains a controversial subject, and license limitation has resulted in little economic efficiency among fishing fleets on the Pacific coast.

## OTHER FISHERY-MANAGEMENT OBJECTIVES AND CONSIDERATIONS

As with most public resources, a variety of special considerations and objectives guide fishery-management decisions. Most important objectives are stated in the Magnuson Fisheries Conservation and Management Act (MFCMA), the broadest piece of fisheries legislation to date. The MFCMA establishes Regional Fishery Management Councils to develop marine fishery-management plans for use by the U.S. Department of Commerce. The MFCMA sets out national standards for fishery management, which include: preventing overfishing, achieving "optimum" yields, promoting efficiency in the use of resources, and minimizing costs "where practicable." Optimum yield is defined broadly enough to include adjustments to escapement in anadromous fisheries for economic, social, or ecological reasons.

Current policies in fishery management attempt to maintain high fish populations and annual yields, while addressing socioeconomic factors such as maintenance of jobs and incomes in the many coastal communities that depend on the fishery. Another objective is the equitable division of available fish among competing user groups. The Pacific Fishery Management Council's Salmon Plan (1983), for example, provides for a 30-percent share of coho salmon for recreational fishing off the Oregon coast and the Columbia River. Also, allowable annual catches of salmon in the ocean-troll fishery are set with the intention of permitting the escapement of salmon to "inside" (protected water) net fisheries.

## IMPLICATIONS FOR ECONOMIC EVALUATION OF ANADROMOUS FISH HABITAT

Given the economic problems of open-access fisheries under their existing management, how should we evaluate a prospective increase in salmon stocks contributing to the fisheries? In the commercial fishery, no net economic yield will occur when harvests are increased if more fishing vessels enter the fishery. Resource management authorities have consistently failed to generate a rental value for fisheries. This failure suggests that other objectives, such as fisheries employment or freedom of choice in fishing occupations, were considered more important. One could then argue that these other objectives must have been worth at least what was "paid" for them. Maintenance of additional employment in coastal communities, for example, could be counted as a benefit, but this argument assumes too much about the knowledge and intentions of public decisionmakers. If other social or cultural objectives are achieved at the expense of economic efficiency, they need to be evaluated and justified on their own merits.



Prospects for generating net economic yields from commercial fisheries are not so bleak as the simple bioeconomic model suggests, however, if recently established license-limitation programs prevent some of the potential new investment in the fishing industry. For marginal growth in anadromous stocks, one could assume that additional harvests involve no additional costs, because sufficient capacity is already available. Some increase in fishing effort would probably be necessary to take additional catch, however, and this effort involves some incremental cost. Thus, for increments taken by fishing fleets whose capacity is rigidly controlled, only the incremental costs of increased capital depreciation, consumable supplies, and labor hired away from alternative employment need be subtracted from market value to determine net economic value accruing to producers. Both Meyer (1982) and Crutchfield and others (1982) suggest that about 90 percent of gross ex-vessel value of marginal harvest is net value. This figure applies only so long as the fishing industry is prevented from expanding its capacity in response to the increased catch.

In addition to this net value in commercial fishing, consumer surplus is generated in both the commercial and recreational fishing sectors. Neither of these values has been sufficiently documented to be used for practical assessments, but both could be important in preserving and improving salmon habitat. Finally, nonmonetary factors, such as maintenance of fishing communities, cultural traditions, and a sometimes attractive lifestyle, must be counted as benefits of anadromous fish stock management. More comprehensive studies of these factors may allow us to assign a monetary equivalent to these benefits.



## MANAGEMENT OF FRESHWATER HABITAT

### DEPENDENCE OF ANADROMOUS FISH PRODUCTIVITY ON HABITAT

Anadromous salmonids of western North America have an extensive geographic range extending from the McKenzie River on Alaska's north slope to southern California. Habitats within this range are used by eight species of anadromous salmonids. Certain geographic areas are dominated by one species, but several species almost always cohabit within the range. Habitats within much of the range of anadromous salmonids are found in coniferous forests.

Anadromous salmonids use freshwater, estuarine, and marine environments to complete their life cycles. Habitat requirements are exacting for all species. All accessible freshwater environments, and an extensive variety of microhabitats, are used by anadromous salmonids at some stage in their life history. Most reproduction occurs in fresh water, although some species occasionally reproduce in brackish intertidal areas. Juveniles of most species rear in fresh water for some time before migrating to the



sea where they mature. For optimum production all species require: water between 5.6 and 14.6 °C; free migratory access to and from the sea; clean gravel substrate, with less than 10 percent sediment smaller than 1-mm diameter, for reproduction; water with turbidity of less than 50 NTU (nephelometric turbidity units) during the growing season, for sight feeding; dissolved oxygen greater than 6 mg/liter in streams, lakes, and the intergravel environment; and invertebrate organisms for food (Everest and Harr 1982). Species preferences for these habitat variables differ slightly and are presented in detail by Reiser and Bjornn (1979).

Natural habitats are important in maintaining viable populations of wild anadromous salmonids. Because most waters support several species of anadromous salmonids, natural habitats must contain a diverse and complex set of depths, velocities, substrates, and cover, in addition to having adequate water quality, to meet the needs of several life stages of cohabiting species. Any environmental manipulations that simplify habitat will have a direct, negative effect on fish population structure and abundance. Because the ranges of anadromous salmonids and coniferous forests are largely coincident, forest management rather than range management will likely have the greater influence on salmonid habitat in the long run.

## EFFECTS OF FOREST AND RANGELAND MANAGEMENT ON ANADROMOUS FISH RUNS

Links between forest management and fish production are complex and depend on many environmental variables. A physical disturbance created by forest management, interacting with the physical and biological features of the environment, can have either minor, major, or neutral effects on fish habitat. The general effects of forest management on habitat of anadromous

salmonids have been documented by several studies. Effects range from drastic changes in physical habitat and fish populations to no apparent change in either habitat or fish numbers, depending on prescribed treatment.

Timber-management activities and logging-road construction have three primary effects on salmonid habitat. These activities tend to increase sediment and temperature in streams while reducing the source of large woody debris--the primary structural component of habitat in small streams. Other effects include changes in water chemistry resulting from timber cutting, burning, or use of forest chemicals, and an increased biochemical oxygen demand (BOD) caused by addition of fine organic debris to streams. Minor changes in streamflow also occur. A few studies have shown that these effects, singly or in combination, have decreased the standing crop of salmonids. Most studies, however, have only assessed the effects of timber management on habitat, rather than on salmonids, because assessing fish populations is a long-term, expensive operation. Consequently, the relation of habitat changes caused by logging to populations of juvenile salmonids needs further documentation (Everest and others, in press).

Salmonids are able to tolerate some short-term habitat disturbances because of their natural compensatory mechanisms, such as high reproductive rates and a fairly broad scope of physiological and behavioral responses. Salmonid populations have always had to cope with short-term natural habitat disturbances, such as floods, sedimentation from landslides, scouring of stream substrates, and deposition of organic debris in streams. These disturbances occur with varying frequencies and magnitudes, and may depress fish production in the short run.

The frequency of these events, however, is often accelerated by timber-management activities, and the construction and use of forest roads. Frequent occurrences sustained in intensively managed watersheds can produce cumulative effects that can cause long-term decreases in salmonid productivity.

These accelerated events, by themselves, probably would not completely eliminate salmonids from forested watersheds, even in a worst-case situation (Salo and Cederholm 1981). When the cumulative effects of logging activities on freshwater life-history stages are combined with an intensive harvest of fish stocks in both fresh and saltwater, however, and imposed over natural mortality rates of salmonids, fish production can drop below the level needed for desired seeding.

Removal of the forest canopy adjacent to and within the riparian area has the greatest effect on salmonid habitat. This removal raises summer water temperatures (Moring and Lantz 1975), lowers winter water temperatures (Chapman 1962), and reduces the amount of terrestrial insect drop and litterfall into streams (Toews and Brownlee 1981). Canopy removal may also reduce bank stability, thereby increasing the amount of sediment entering the stream (Sedell and others 1982). In time, it will also reduce or eliminate the addition of large organic debris, which in turn will result in less structural complexity within the stream. Not all of the effects are detrimental, however; increased light reaching the stream can temporarily increase the production of algae and sustain greater densities of drifting invertebrates, which form the basic diet of fish.

Fauna and flora are often more abundant in sections of streams with open canopies than in forested sections (Aho 1976, Albrecht 1968, Erman and others 1977, Gregory 1980, Hughes 1966, LeCren 1969, Lyford and Gregory 1975, Murphy and Hall 1980, Newbold and others 1980, Thorup 1966). Removing streamside vegetation increases aquatic production at the lower end of the food chain. This production is a result of increased light, which stimulates growth of algae and periphyton (Gregory 1980, Murphy and Hall 1980). Many reports on logging effects, however, emphasize the destructive potential of accumulated sediment that adversely affects stream habitat (Cordone and Kelly 1961, Gibbons and Salo 1973, Iwamoto and others 1978). The long-term loss of large woody debris is equally detrimental. Thus, logging may have two opposing localized effects: canopy removal, tending to increase basic stream productivity; and sedimentation and loss of large woody debris, tending to decrease productivity.

Murphy and others (1981) found that small, open sections of streams passing through clearcuts had a greater density, biomass, or both of invertebrates and cutthroat trout than did shaded, forested reaches, regardless of sediment composition. They concluded that, for small streams in the Cascade Range, changes in fish-food status and increased production of algae resulting from shade removal masked or overrode effects of sedimentation. Their data indicate that strong links exist among amount of light reaching the stream, primary production, invertebrate production, and--ultimately--vertebrate production. Gregory (1980) found periphyton production in small streams in a western Oregon study area to be light limited. Chapman and Knudsen (1980) found that fish production in some Puget Sound streams was indirectly light limited.



Thus, canopy removal in small blocks can positively influence stream productivity, but cumulative effects of extensive cutting could cancel any potential benefits. Sedimentation and canopy removal both have adverse effects in the long run. Increases in sediment load can cause the stream to become wide, shallow, and unstable, often with a braided channel (Leopold and others 1964). Filling of pools with sedimentary material reduces suitable habitat for trout (Bjornn and others 1974) and damages spawning habitat. These effects of sediment are not usually observed in sites where large woody debris creates a stairstep channel profile, and forms plunge pools downstream of debris accumulations (Keller and Swanson 1979, Meehan and others 1977). Canopy removal and stream cleanup usually cause a substantial loss of the large woody debris that can mitigate the effects of sediment. Canopy removal rarely increases stream temperatures enough to kill trout (Martin and others 1981, Moring and Lantz 1975), but sublethal increases can indirectly affect survival, and cumulative effects can reduce the quantity and quality of rearing habitat in downstream waters.

Physical habitat for anadromous salmonids has been altered in the last two decades by a combination of increased sedimentation, channel sluice-outs, and excessive debris removal related to timber management. The cumulative result has been a loss of large, high-quality pools necessary for rearing juvenile salmonids and holding adult salmon before they spawn. Most high-quality pools in small streams are formed by large tree-sized debris.

Also, most high-quality cover in small streams is provided by large organic debris. Overzealous cleaning of the channel, or failure to provide a long-term supply of large organic debris after cutting, can turn a productive stream that is suitable for salmonids of a wide range of sizes and ages, into a marginal stream suitable primarily for underyearling fish (Bisson and Sedell, in press). Coho salmon and cutthroat trout habitat generally is reduced in this manner in exposed and cleaned streams. The loss of high-quality pools removes temperature refuges as well. Big pools, in both small streams and large rivers, tend to stratify thermally in summer, providing cool-water refuges in areas where cool surface water or ground water enters the stream and collects (Everest 1973).

## ECONOMIC CHARACTERISTICS OF INSTITUTIONS

Like stocks of ocean and river fish, freshwater habitat also suffers from the common-property curse. Although a variety of legal and administrative institutions allocate and assign rights to riparian areas and access to surface water, rights to much anadromous fish freshwater habitat remain unassigned. As a consequence, when an activity such as logging or mining damages the habitat, the damage does not appear as a cost of production to the offending firm. Without public regulations in sensitive areas, logging or mining can cause excessive damage to the habitat. Imagine some economically efficient system in which property rights to freshwater habitat are owned by private citizens (this is close to the actual situation in parts of the United Kingdom). Then, the habitat owner would require compensation from a logging firm up to an amount equal to the value of fishing lost. The logging firm would have strong, economic incentives to avoid habitat damage and to log where fishing values are least affected.



Under current laws, however, logging practices are publicly regulated. These regulations, in effect, are a substitute for the discipline of the private market that does not exist for habitat or fishery resources. Because regulations are formed in a public forum, various criteria for management of habitat need to be considered and agreed on.

## ECONOMIC CRITERIA FOR MANAGEMENT

Each watershed, along with its anadromous fish stocks, forests, and rangelands, can be treated as a complex resource with multiple uses. Resource management should seek to raise the total net value of all resource uses. But some uses, such as fishing and logging, impinge on each other's potential value. Similarly, camping and back-packing may be incompatible with some forestry practices. Some different classes of recreational use, such as wilderness camping and developed motor-home camping, cannot use a given area simultaneously without conflict. Optimal use of forest lands requires balance among competing uses.

The broadest conclusion from economics is that each use should be adjusted until the marginal net value of one is equal to the marginal net value of all other uses. Thus, any increase in timber cutting should have a net economic value at least equal to the net economic value of fishing, camping, or other uses that is lost because of additional cutting. If the fishing or camping opportunities lost because of timber operations on a particular plot are worth more than the timber products, then the timber should not be cut. Where the timber value is greater than the fishery or recreational value, the timber should be cut. To achieve a balance in any case we need to know the marginal net values generated in fisheries, and the costs of efforts by management agencies and commercial enterprises to preserve or improve anadromous fish runs.

## MARGINAL NET VALUES GENERATED IN FISHERIES

Improvements in freshwater habitat increase sustainable fishery yields for the major fisheries. Thus, marginal economic value in habitat management is expressed as the increase in harvest as a result of improved habitat times the marginal value of additional fish. Further, the value of additional sustainable harvest depends on how that harvest is allocated among commercial, recreational, and subsistence fisheries.

If fishery managers had exact control over the allocation of fish among users, they could achieve maximum value by allocating to highest valued uses first. Noncommercial uses having a higher value than the commercial harvest would probably be satisfied first, and the remainder allocated to the commercial harvest. This allocation would have little effect on the commercial price of salmon because of their large international market.

Placing values on net changes in fishery production would be simplified under the above allocation because marginal changes in production would primarily be changes in commercial harvest. The commercial value would therefore be the relevant value for that marginal change in production.

Fishery managers, however, have neither the capability (as long as the commercial catch from mixed stocks in the ocean is large) nor the desire to allocate fish in that manner. Thus, the actual change in value from marginal changes in fish production is an average of values for different uses that is weighted by the proportional allocation.

The net economic values from commercial harvests may be quite low when open access allows excessive numbers of fishing firms to compete for limited quotas. All ocean salmon fisheries on the Pacific coast, however, are currently under license-limitation systems and have sufficient capacity to harvest additional fish. Thus, approximating the marginal net economic value of improved or restored fish runs as the ex-vessel price of fish, minus the marginal increase in operating costs required to take the additional catch, is becoming increasingly acceptable. Under these conditions, the net value of a small increase in fish may be 90 percent of the ex-vessel value. This figure ignores possible increases in consumer surplus in retail markets, but most improvements in freshwater habitat will be small enough to make this an acceptable simplification.

Marginal values of anadromous fish to recreational fisheries have not been reliably estimated. The daily value of recreational fishing is undoubtedly greater when the daily catch is increased, and the seasonal fishing value for any fish run is greater when the run is greater. But the contribution of an increased run to either a daily or seasonal catch depends on the nature of the fishery and the fish run. Thus, the incremental contributions of fish runs to recreational values are hard to estimate.

Subsistence and Indian-treaty fisheries have not been studied extensively by economists to estimate net economic values. From an economic perspective, fish harvested by these groups would be valued differently. The treaty fishery is primarily an assignment of property rights to harvest fish to a particular segment of the commercial sector. Special cultural considerations may attribute a high value to a portion of the harvest tied to cultural-religious traditions. Beyond that, the harvest going to commercial markets would be valued much the same as the remainder of the commercial harvest, and this value would apply to

marginal changes in harvests. Because under Indian treaties fish are generally harvested by less costly methods than other commercial harvest, the net economic value per fish may be somewhat higher in the treaty fishery.

Subsistence fishing in Alaska is by law for personal use or barter only. Subsistence fishing was at one time open to all residents; now it is limited to people residing in rural areas and small towns. Because no qualifying income test is used, some subsistence fishing is done by people of above-average means. The net economic value of marginal changes in subsistence harvest is probably somewhere between the ex-vessel value of the commercial harvest and the replacement cost of the fish in the diets of subsistence users. As with treaty fishing, some portion of this fishery may have a cultural-religious aspect.

#### COSTS INCURRED TO PRESERVE OR ENHANCE ANADROMOUS FISH RUNS

Current State and Federal forest-practice guidelines in the Pacific Northwest require protection of fishery resources during all timber harvest operations. This protection can cause out-of-pocket or opportunity costs to responsible timber-management agencies, private timber companies, and contractors. Protection of fish habitat results in increased cost to timber managers in the following activities: constructing and maintaining roads; protecting riparian vegetation; and maintaining and protecting habitat structure within streams.



Roads affect fish habitat primarily by accelerating sedimentation, infringing on stream channels and floodplains, and restricting fish passage. To alleviate sediment and infringement problems, roads in steep, unstable terrain should be avoided, or located on or near ridgetops, using varied grades to take advantage of favorable topography. Adequate drainage relief should be provided (Wenger 1984), and fish-bearing streams should be crossed on bridges or open-bottom culverts. Construction standards often require minimum road width and full-bench subgrade. Roads built to lesser standards often accelerate erosion and stream sedimentation (Fredriksen 1970, Megahan and Kidd 1972) and degrade habitat. The exact benefits of these activities to fish production, however, are hard to determine and each case must be examined individually. Most features of road location and design that benefit fisheries also provide long-term benefits to forest transportation systems. Although roads built to new, demanding standards are more costly, they are also less subject to cut-and-fill failures, and require less maintenance and reconstruction than roads built to lower standards. A complete analysis requires that all of the benefits from such roads--to timber management, fisheries, and other resources--be included in the benefit-cost equation whenever road construction or reconstruction is planned. At the planning stage, estimating the increased cost of construction is relatively easy, but determining the benefits of reduced maintenance costs and of less closure time because of road failures is much more difficult.

Protection of riparian vegetation and instream fish habitat also requires out-of-pocket and opportunity costs for timber managers. Timber managers must often use specialized timber felling and yarding practices to maintain riparian buffer strips. Directional felling of timber away from buffer strips by lining or jacking is a proven way to protect riparian vegetation. Directional (uphill) felling on steep, broken terrain is also safer for felling crews and reduces breakage of old-growth timber (Burwell 1971, McGreer 1975), resulting in increased recovery of wood fiber. The costs of directional felling are about three times greater than for conventional felling, but the benefits of directional felling in old-growth timber stands, based on increased fiber recovery alone, are often sufficient to pay the added costs. Several private timber companies use this technique to increase their timber production.

Large woody debris in streams is a critically important structural feature of fish habitat in forested watersheds. Fallen trees with attached rootwads and limbs provide the diversity and complexity of habitats required by the different species of salmonids residing in streams of the Pacific Northwest and Alaska. Because wood in aquatic systems has a finite lifespan, forest managers must provide a streamside source of large trees that will enter the stream channel, in the form of large organic debris, more or less evenly over time. Leaving commercial timber in buffer strips for this purpose may represent a substantial opportunity cost. The placement of artificial stream structures to compensate for the removal of riparian trees can also be costly, however. For example, a sound Douglas-fir, 36 inches in diameter, has an estimated volume of around 3,000 board feet. The stumpage value of such a tree could range from under \$300 to over \$1,200, depending on market conditions and location of the tree. The cost of installing a gabion structure to maintain a desirable stream habitat may range from \$500 to \$1,500, depending on its dimensions.



Because physical and economic characteristics differ among locations, both commercial and recreational values of a given stream habitat will differ also. Economic reasoning suggests giving greater attention to habitat protection and improvement in some areas than in others. Less productive streams, for example, may justify more aggressive forest practices, and more productive streams should be more strictly protected. Similarly, where timber inventories are less valuable, more timber should be left standing to protect stream habitat. Taking such variable factors into account, however, requires a high degree of knowledge and confidence about both physical and economic systems. Uniform rules of forest and range usage are easier to put into effect.

## PROBLEMS OF IMPLEMENTATION

Economic considerations set forth in this paper should, ideally, improve management policies for freshwater anadromous fish habitat; however, economic criteria cannot, and should not, dominate policy formulation. Translating economics into specific rules is often difficult and fraught with uncertainty because of both a lack of well-developed economic models and a lack of data. The economic value of commercial fisheries depends on biological-yield potential, harvesting costs, and market demands. But uncertainties in biological assessments of potential yields leave most practical management decisions with order-of-magnitude estimates. Furthermore, harvesting costs depend on management strategies in the fishery, as well as market prices of fuel and equipment used in fishing. Finally, fish prices are subject to a wide variety of influences other than those from the fishery or river system. These factors, and the lack of useful economic studies for most anadromous fisheries, dictate that economic considerations be taken only as general guidelines for management.

Management plans for freshwater habitat are particularly complex and numerous because anadromous fish move from freshwater streams through sensitive estuarine habitats to oceanic feeding grounds, and back to the stream of origin. Individual States and Nations often control only one portion of a fish population's full habitat, which makes unified management of a fish population difficult. The United States' Regional Fishery Management Councils, for example, manage the 200-nautical-mile Fishery Conservation Zone. But many of the chinook salmon from the Columbia River system migrate to the ocean off British Columbia and southeastern Alaska. Inter-regional and international negotiations are necessary for overall management of these fish runs. Landward of the 3-mile territorial limit, States have more authority than the Fishery Councils. Moreover, responsibility for freshwater habitat is split among various State agencies and Federal departments. The interweaving of responsibilities and authorities makes it difficult to turn economically efficient propositions into management rules.

The real choice of policies for freshwater-habitat management is severely limited. Federal and State agencies are often restricted by necessary international compromises. Legislatures rarely allow management agencies to start some of the more economically attractive management methods, such as landings royalties or creation of private-property rights to instream habitat. Given the limited alternatives for managing anadromous fisheries, the economic objectives that can be adopted are limited also. Nevertheless, management must strive to use available natural habitats efficiently by balancing marginal net economic values among alternative uses, and by fairly distributing the economic gains from resource use among participants and citizens.

# METRIC CONVERSIONS

1 inch = 2.54 centimeters  
1 mile = 1.609 kilometers  
1 nautical mile = 1.852 kilometers  
1 pound (lb) = 0.45 kilogram



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# The Role of the Genus *Ceanothus* in Western Forest Ecosystems



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This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed have been registered. All uses of pesticides must be registered by appropriate State or Federal agencies before they can be recommended.

# **The Role of the Genus *Ceanothus* in Western Forest Ecosystems**

**Susan G. Conard,  
Annabelle E. Jaramillo,  
Kermit Cromack, Jr., and  
Sharon Rose  
Compilers**

**Report of a workshop held November 22-24, 1982  
Oregon State University, Corvallis, Oregon**

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## Abstract

Conard, Susan G.; Jaramillo, Annabelle E.; Cromack, Kermit, Jr.; Rose, Sharon, comps. The role of the genus *Ceanothus* in western forest ecosystems. Gen. Tech. Rep. PNW-182. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1985. 72 p.

This report was developed from discussions on the role of *Ceanothus* in western forests that took place at a workshop held November 22-24, 1982, at Oregon State University, Corvallis, Oregon. The workshop provided a forum for discussing research relevant to *Ceanothus* management. Major topics were autecology and synecology; interactions between *Ceanothus* species and the soil system; the physiological ecology of *Ceanothus* and associated conifers; and the effects of *Ceanothus* on forest productivity and growth. The workshop was attended by scientists and land managers from government agencies, universities, and forest industry. This report summarizes available information concerning the biology and ecology of *Ceanothus* species in western forest ecosystems; describes and critiques methods, results, and conclusions of past research; discusses current investigations; identifies research needs; and includes an extensive bibliography and a listing of workshop participants involved or interested in *Ceanothus* research and management.

Keywords: *Ceanothus*, competition (plant), ecology (plant), autecology (plant), synecology (plant).





# 1. Introduction

The impacts of native, symbiotic, nitrogen-fixing plants on conifer productivity, vegetation dynamics, nutrient cycling, and wildlife habitat in forest ecosystems are of considerable ecological and economic interest. The two major genera of nitrogen-fixing woody plants on forest sites in the western United States are *Ceanothus* and *Alnus*.<sup>1/</sup> Although *Alnus* is an important component in coastal and mesic low- and high-elevation forests of the Pacific Northwest, the primary nitrogen-fixing shrubs on drier and middle-elevation forest sites are species of *Ceanothus*. Several of these species are frequently dominant components in early successional vegetation following disturbance such as fire.

Two recent publications (Gordon and Wheeler 1983, Gordon and others 1979) provide an excellent overview of current research on the effects of nitrogen-fixing species on forest site productivity; the biology, ecology, and physiology of the host-symbiont relationship; options for integrating nitrogen fixers into forest management; and economic considerations in the management of symbiotic nitrogen fixers. Although these publications summarize much of the available data on *Alnus* and other species, the information they present pertaining to *Ceanothus* is limited.

A fairly large body of research information exists on the biology and ecology of forest species of *Ceanothus*. The literature indicates that *Ceanothus* affects many components of the forest ecosystem, including nitrogen availability, nutrient cycling, conifer establishment and growth, and forage quality for browsing animals.

The workshop on *Ceanothus* was initiated because widely divergent opinions exist among scientists and land managers concerning the relative benefits and negative impacts of *Ceanothus*. The workshop was structured to provide a forum for discussing major research areas relevant to *Ceanothus* management. The three major objectives of the workshop were: (1) to summarize available information concerning the biology and ecology of *Ceanothus* species in western forest ecosystems; (2) to discuss research methods, results, conclusions, and interpretations; and (3) to identify future research needs. Participants included scientists and land managers from government agencies, universities, and forest industry.

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<sup>1/</sup> Scientific and common names of species are listed in appendix 1.

Following an overview presentation on the importance of *Ceanothus* species in U.S. forest ecosystems, the workshop was organized into small working groups, each of which focused on one of the four topic areas:

1. The autecology and synecology of *Ceanothus*.
2. Interactions between *Ceanothus* species and the soil system.
3. The physiological ecology of *Ceanothus* and associated conifers.
4. Effects of *Ceanothus* on forest productivity and conifer growth.

Past and current research was discussed in each group; the objective was to summarize available information and identify promising techniques for new or improved studies. Emphasis was placed on including existing studies on *Ceanothus* within a framework of long-term research objectives.

Each participant was provided a preliminary bibliography and a list of recommended reading prior to the workshop. Participants were also encouraged to discuss unpublished research.

This report summarizes and updates workshop presentations and discussions. The introductory remarks by Jerry Franklin and the concluding remarks by John Gordon are based on transcripts from tapes. Summaries of group discussions (sections 3-7) include pertinent published and unpublished results identified by participants, comments on research methods and approaches, and recommendations for future research. These summaries were prepared by the compilers.

## **2. The Importance of *Ceanothus* Species in U.S. Forest Ecosystems<sup>1/</sup>**

This paper discusses autecology, distribution, and taxonomic relationships of the major forest species of *Ceanothus* and considers some of the various roles that *Ceanothus* plays in western forest ecosystems.

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<sup>1/</sup> This section prepared by Jerry Franklin, chief plant ecologist, Forestry Sciences Laboratory, Pacific Northwest Forest and Range Experiment Station, Corvallis, OR 97331; Charlie Halpern, research assistant, Botany Department, Oregon State University, Corvallis, OR 97331; Brad Smith, research assistant, Botany Department, Oregon State University; and Ted Thomas, research assistant, Forest Science Department, Oregon State University.

*Ceanothus* is a North American genus of Sierra Madrean origin. Of the 55 species in the genus, 51 of them are found in western North America, four are found in the Eastern United States, and two are isolated in Florida. There are 44 species in the Pacific coast region; 38 of these are restricted to the California floristic province, which includes California, Baja California, southwestern Oregon, and western Nevada. Six species are found in the Rocky Mountains.

Species in the genus *Ceanothus* range from mat-forming shrubs less than 0.3 meter (1 ft) high to small trees as tall as 4 to 9 meters (15-30 ft). Typically, they are shrubs 0.9 to 2.4 meters (3-8 ft) tall. The genus contains both deciduous and evergreen species.

**Genus sections.**—Two sections of the genus are recognized, *Euceanothus* and *Cerastes*; within each section, the species are highly interfertile. There are many known hybrids, which may account for the variability in the taxonomic treatment of the genus—our treatment follows McMinn (1942). The potential for hybridization and formation of species that can adapt to new environments may be one reason the genus has been successful.

The more ancient section is *Euceanothus*, and it contains about 60 percent of the species (approximately 33). Characteristics of several distinctive species are shown in figure 1. Most have retained the ability to sprout. This is also the section in

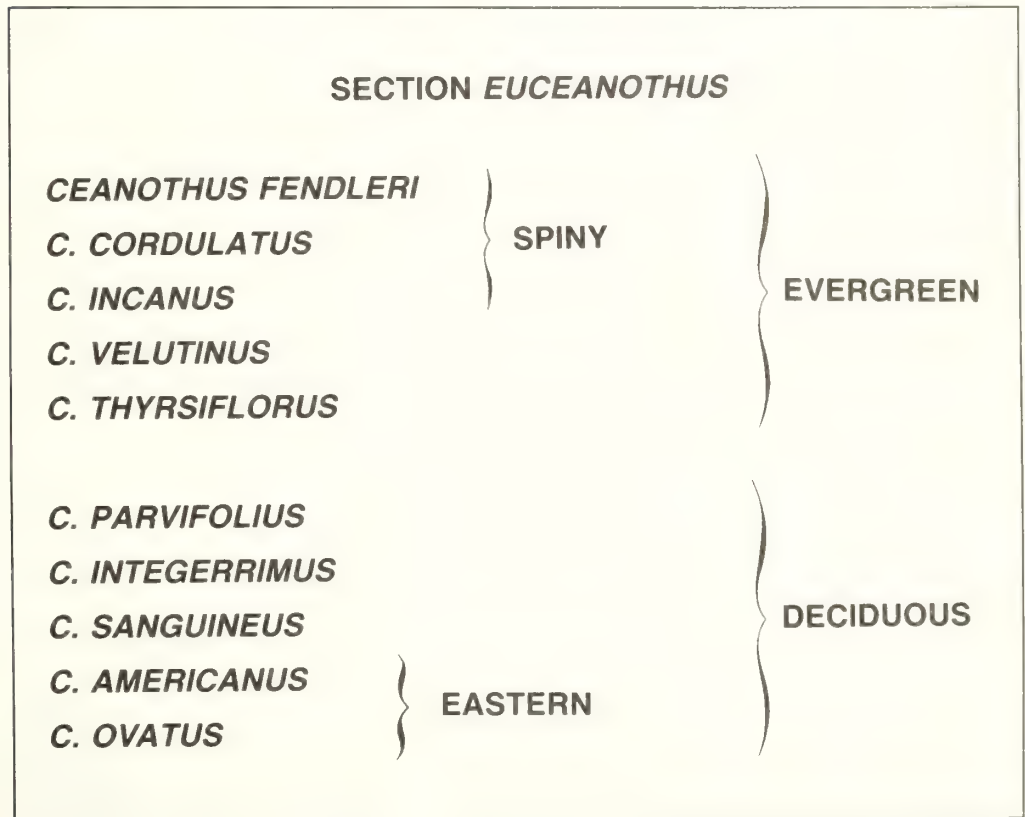


Figure 1.—Ecological characteristics and common forest species of section *Euceanothus* in the genus *Ceanothus*.



which most of the important forest species are found. Both evergreen and deciduous species and both spiny and nonspiny species are included. The four species in the Eastern United States are found in this section.

The other section, *Cerastes*, has about 26 species, and some people believe it contains the most long-lived ones. The species in this section do not sprout, and only a few of them are important forest species (*C. cuneatus*, *C. prostratus*, and *C. pumilus*). *C. greggii* is, however, an important desert and chaparral species (USDA Forest Service 1937). The purported longevity of these species supports a hypothesis that seed reproduction rather than sprouting tends to be characteristic of long-lived species.

**Distribution.**—Many *Ceanothus* species occur in chaparral and desert habitats at elevations below forest sites or at the forest-nonforest interface. Approximately a third of *Ceanothus* species (20 to 25) are forest oriented. These species, with a few exceptions, are important components of the communities in most western forest zones except in the coldest zones and in moist habitats, such as the Sitka spruce zone and the wetter parts of the western hemlock zone. Generally, *Ceanothus* species are not found in subalpine forests except at the lowest elevations of the zone. *Ceanothus* distribution is skewed toward the driest forest zones—ponderosa pine and the Douglas-fir series—and toward early successional stages of midslope zones in the Rocky Mountains, the Sierra Nevada, and the Cascade Range. This includes the mixed conifer zone of the Rocky Mountains, the mixed conifer forests of the Sierra Nevada, and the midslope forests on the east slope of the Cascade Range.

The West is divided into several major habitat regions (fig. 2). In the northwestern area, *Ceanothus* are very common seral species in some parts of the western hemlock zone, in the lowest parts of the Pacific silver fir zone, and especially in habitats where Douglas-fir is the climax species. In southwestern Oregon and northern California, *Ceanothus* species are represented in all the forest zones, from the driest (Douglas-fir) through the more moist tanoak, western hemlock, white fir, and red fir zones and are associated with Jeffrey pine on serpentine habitats. In the Sierra Nevada and the Coast Range of California, *Ceanothus* species are very important in the chaparral and extend into the Digger pine and oak woodlands and all of the forested zones, including the red fir and Jeffrey pine forests at higher elevations. It is also an important genus in the knobcone pine forests. In the northern Rocky Mountains, *Ceanothus* is a component of most of the important forest zones except for the upper part of the subalpine forest. *Ceanothus* are seral species of western hemlock and western redcedar zones in northern Idaho and western Montana. Utah, Colorado, Arizona, and New Mexico have only one species, *C. fendleri*, which is found primarily in the ponderosa pine zone. A possible hypothesis for the absence of many *Ceanothus* species in the southwest is that they are poorly adapted to summer precipitation.

**Physiology.**—*Ceanothus* species are generally intolerant to very intolerant of shade. This has important implications for the successional role that they play. The genus is also very tolerant of stress and can withstand both cold and hot temperature extremes, drought, and poor site conditions.

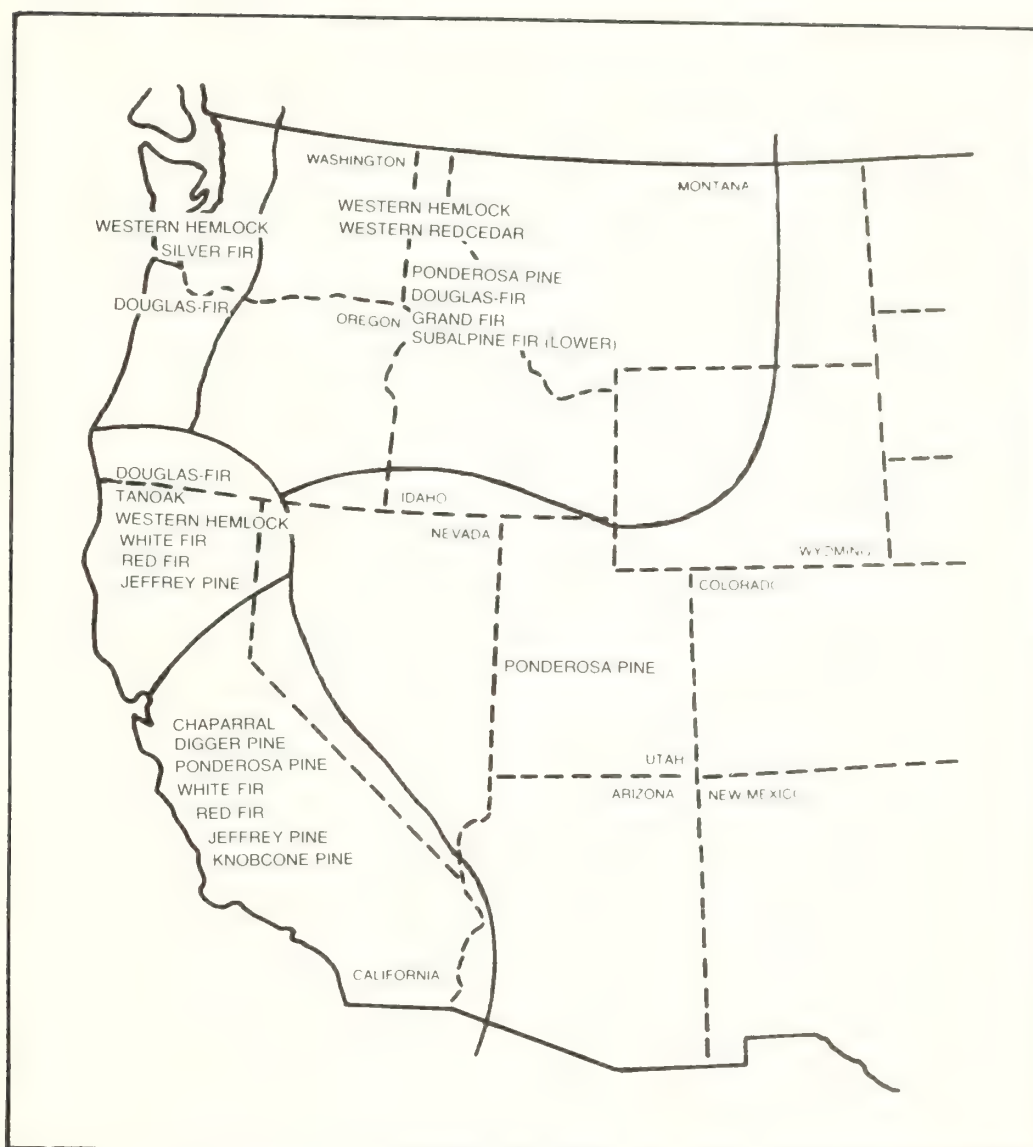


Figure 2.—Zones or community series in which one or more *Ceanothus* species play important roles.

*Ceanothus* species have the potential to fix nitrogen. Although the occurrence of nodules on *Ceanothus* has been known for a long time, demonstration of the ability of the plants to actually fix nitrogen is a relatively recent discovery (Bond 1957). The ability of *Ceanothus* to fix nitrogen has been demonstrated in the laboratory for all species that have been examined in detail. Delwiche and others (1965), for example, worked with 12 species using excised nodules and found that in all cases when these species are nodulated they are capable of fixing nitrogen. Field demonstrations of net nitrogen accretion are much more limited and are somewhat controversial. Probably all the species have the potential to fix nitrogen on at least some sites at least part of the time.

**Reproduction.**—All or most of the species reproduce from seed, which is persistent and is subject to seedcoat dormancy. In the laboratory, most species require a hot water treatment and stratification for germination (Reed 1974). In nature, heat from fires or from other sources, such as the sun, is believed to be the major stimulant to germination. Fire is not absolutely essential for germination of *Ceanothus* seed, but it is the most common and effective way to stimulate germination. Gratkowski's (1962) work on *C. velutinus* shows that heating the seed results in a permanent irreversible opening of the hilar fissure which allows moisture to penetrate. Heat does not affect the seedcoat itself.

Sprouting is not the primary means of reproduction in the genus, although most of the forest species exhibit at least some ability to sprout. There is some confusion in the literature regarding the distinction between sprouting and nonsprouting species. This confusion may result from the fact that species without a root crown burl cannot tolerate repeated, intense burning. This could be why many ecologists say that a particular *Ceanothus* species does not normally sprout. This is especially puzzling as many *Ceanothus* species occur in environments such as chaparral where fire is common. In fact, most or all species have some sprouting ability, although the species in the section *Cerastes* do not normally do so. Even though disturbance is necessary to stimulate seed germination, fire can be either too frequent or too intense, and can eliminate *Ceanothus* species. Seed and plants can be destroyed with repeated burning. For example, if *Ceanothus* is windrowed, the seed can be piled up within intense fuel concentrations. In such situations, much seed is destroyed, and establishment of *Ceanothus* species is often very low.

Wildlife managers express concern about reduced *Ceanothus* occurrence caused by fire control programs. Although some foresters may find it hard to imagine insufficient *Ceanothus*, wildlife experts in some national parks in the Sierra Nevada are concerned that fire control programs may destroy a favorite browse for wildlife.

**Occurrence.**—The successional roles of *Ceanothus* species are a consequence of their combined intolerance of shade and a need for disturbance for regeneration. *Ceanothus* generally occurs in one of two situations: First, it can be a regular component of forest communities that lack a closed canopy and that have some level of disturbance to allow for reproduction of the species. For example, in chaparral, some woodlands, Jeffrey pine stands, and even in some ponderosa pine and Douglas-fir stands, the canopy never gets sufficiently dense to shade out the species. *Ceanothus* could be a basic component of the stable forest on such sites. Second, *Ceanothus* may exist as an early successional species on sites that develop a closed forest canopy; for example, snowbrush (*C. velutinus*) in the mixed conifer forests of the northern Rocky Mountains or in the western hemlock zone of the Cascade Range. These are situations in which *Ceanothus* reproduces following a disturbance such as logging, burning, or wildfire. It grows until it is overtopped by the trees, and it persists as seed until the next major disturbance.

In many young forests, the canopy can be dense enough to shade out *Ceanothus*, but in mature stands there are many canopy openings. Many of the Sierra mixed conifer forests, for example, have a very open canopy and in a mature forest, *Ceanothus* can be a permanent member of those forested communities. Some of the Douglas-fir climax sites in southwestern Oregon and some of the drier sites in the Rocky Mountains are similar. Whether the genus is pioneer or climax, many *Ceanothus* species also have the ability to retard succession by forming brushfields.



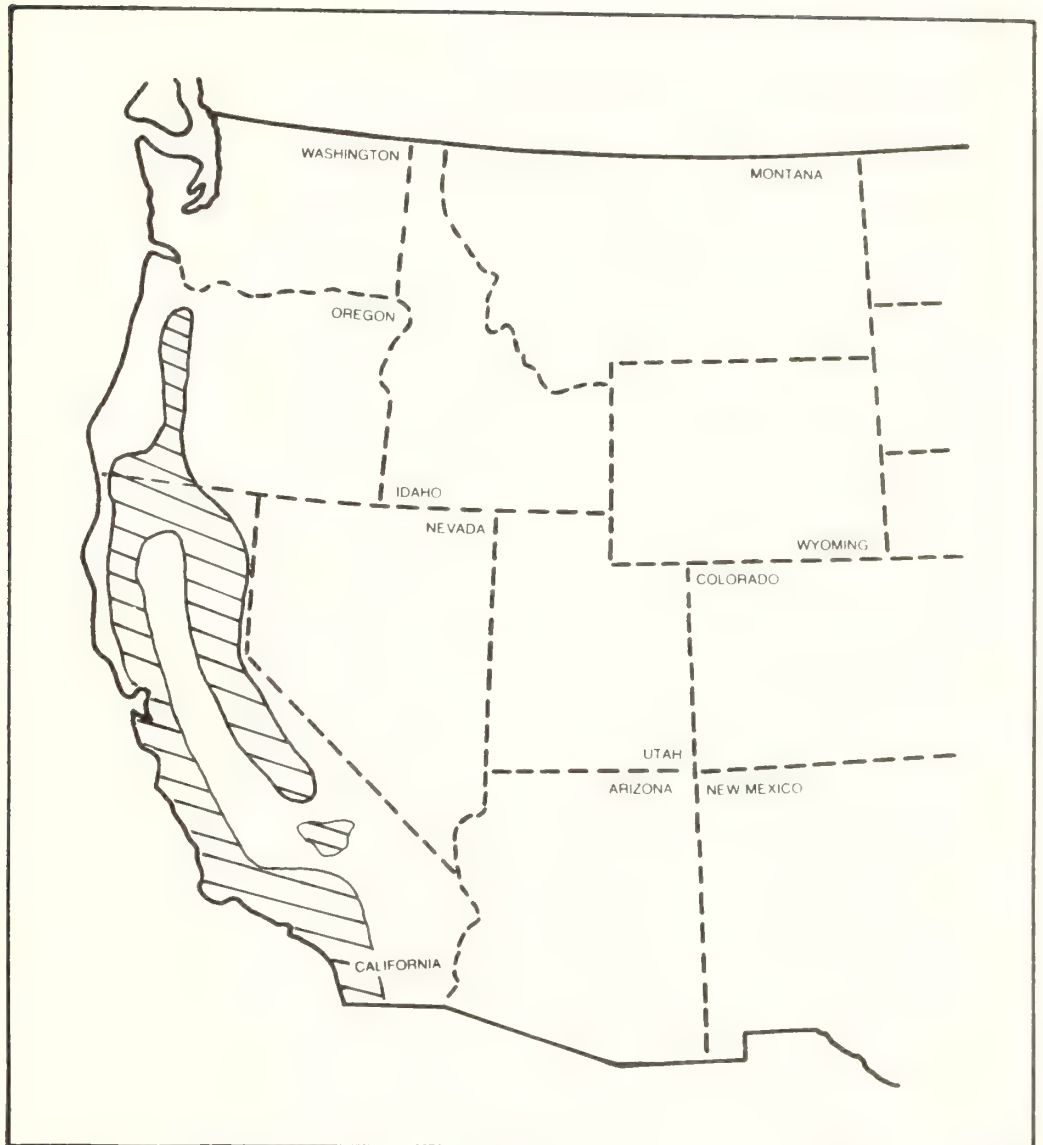


Figure 3.—Distribution of *Ceanothus cuneatus*. Range information from McMinn (1942), Hitchcock and Cronquist (1961), and Sampson and Jespersen (1963).

**Ecology and distribution of selected western *Ceanothus* species.**—*Ceanothus cuneatus*, (wedgeleaf ceanothus or buckbrush, fig. 3) is primarily a chaparral species, but it also occurs in ponderosa pine and other dry forests. Typical of shallow soils and dry sites, it is a very drought-resistant species. It is a vigorous, aggressive species that can form impenetrable thickets. Because of its palatability, it is an important winter food for deer in many areas.

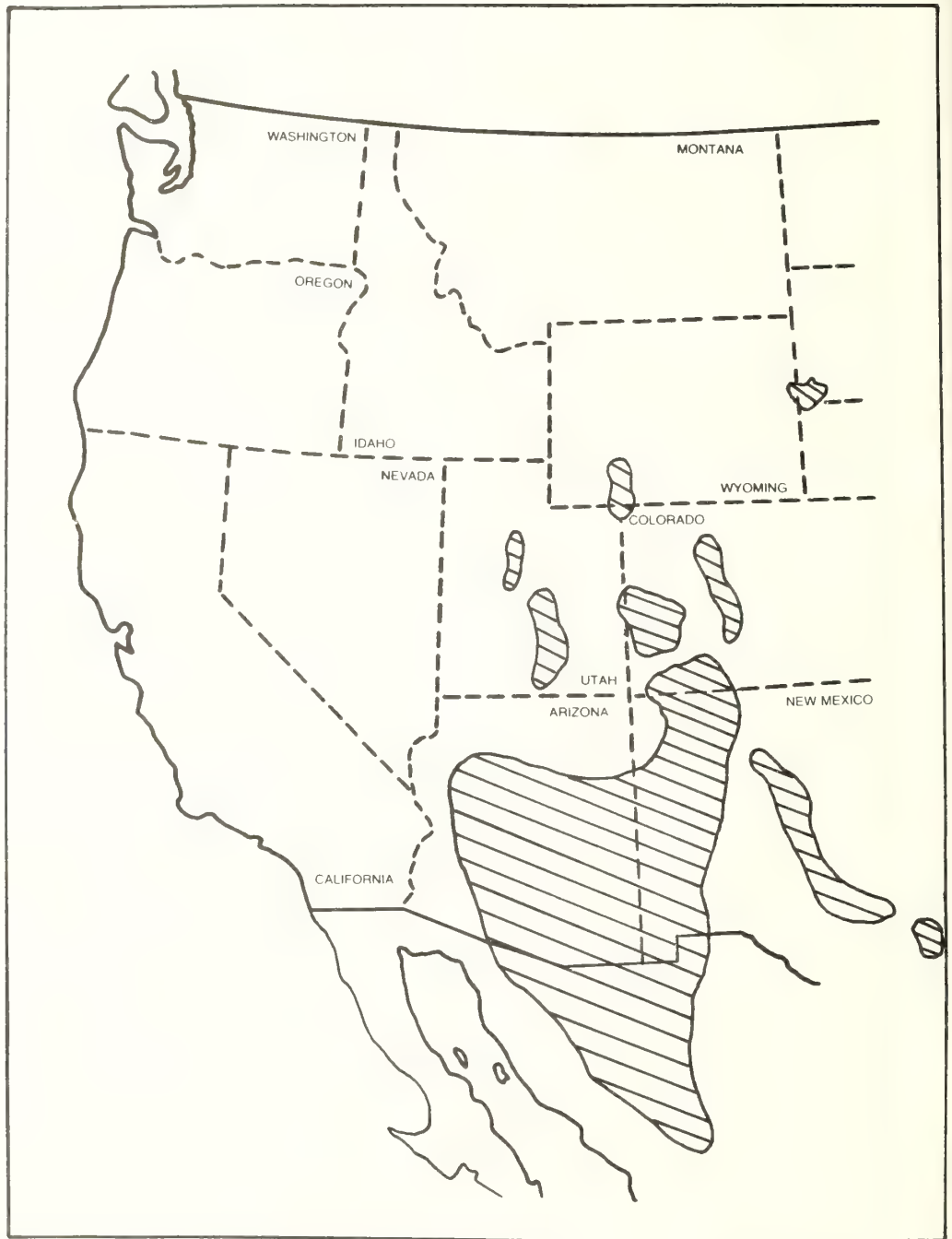


Figure 4.—Distribution of *Ceanothus fendleri*. Information from McMinn (1942).

*Ceanothus fendleri* (Fendler ceanothus, fig. 4) occurs in the ponderosa pine zone in the Rocky Mountains. It also occurs in some of the drier Douglas-fir habitats of the Southwest (Alexander and others 1984) but is generally absent from white fir forests. A nonsprouter, it germinates following fire and is a component of the stable mature forest. *C. fendleri* is an important browse plant for deer and is often mentioned in connection with deer management.

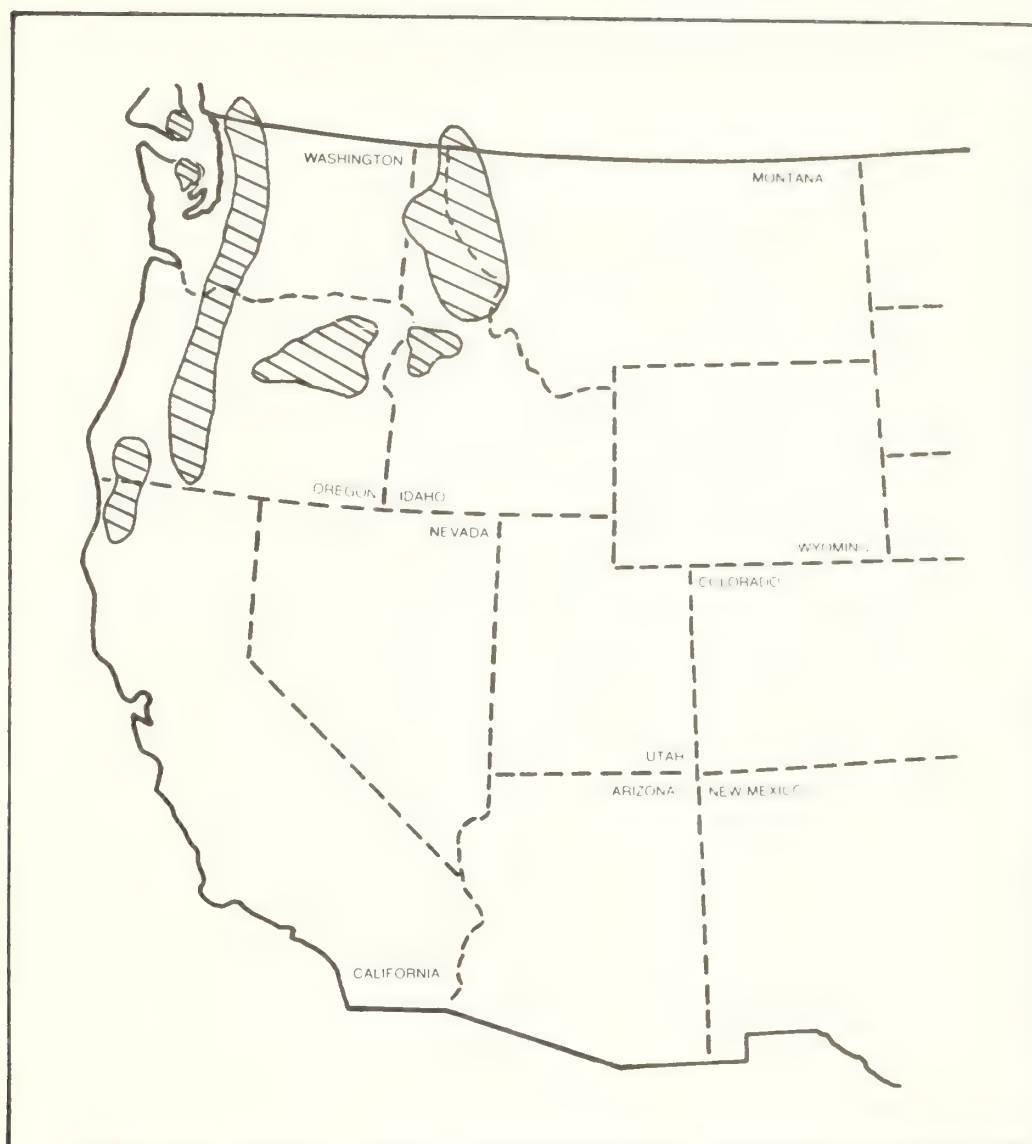


Figure 5.—Distribution of *Ceanothus sanguineus*. Information from McMinn (1942), Hitchcock and Cronquist (1961), and personal observations of the authors.

*Ceanothus sanguineus* (redstem ceanothus, fig. 5) is found primarily in the ponderosa pine zone and in parts of the mixed conifer and western hemlock zones in both the Cascade Range and in the northern Rocky Mountains. In the Cascades, it is common on sites in the Douglas-fir habitat series, particularly after logging and burning. *C. sanguineus* is considered excellent browse for wildlife.



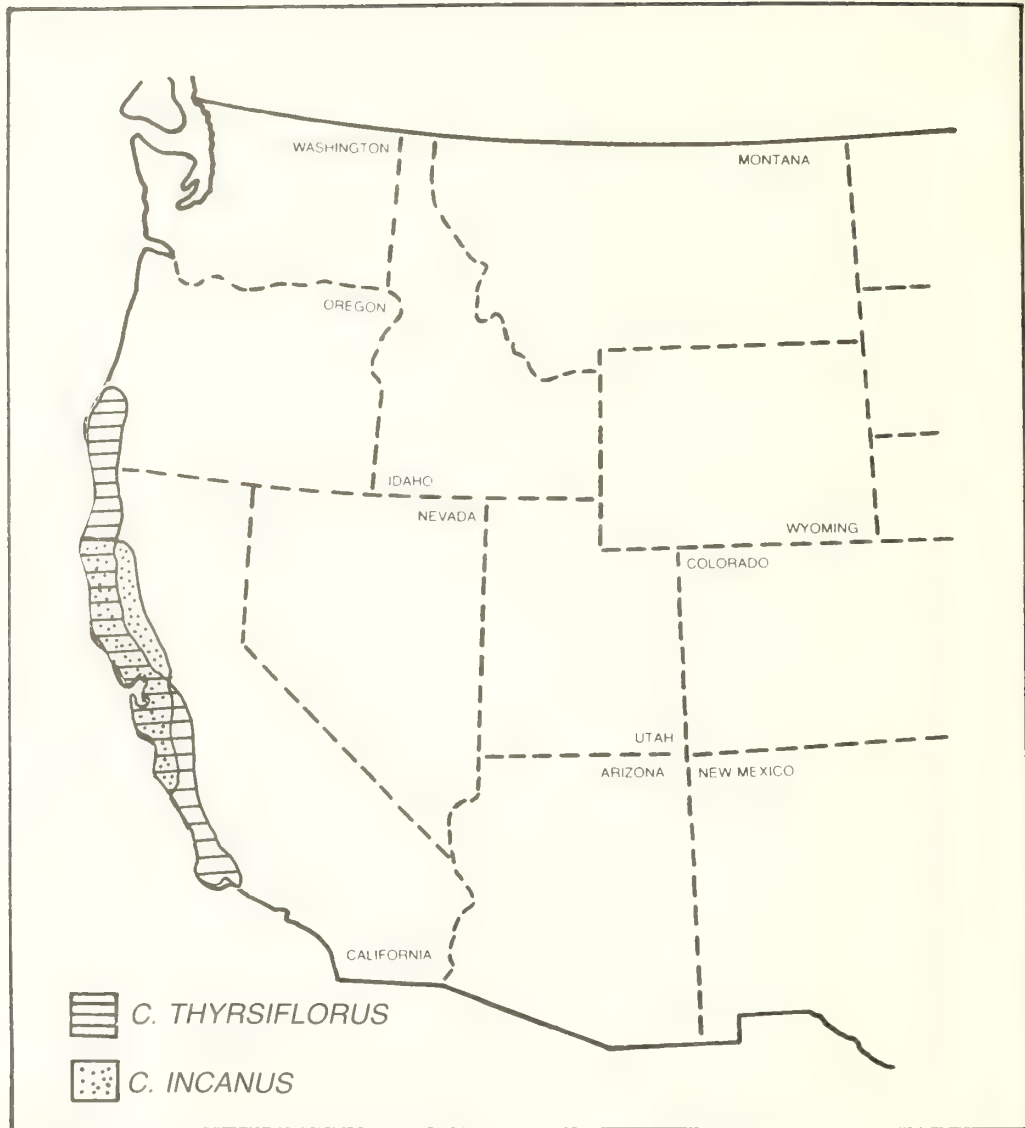


Figure 6.—Distribution of *Ceanothus thyrsiflorus* and *C. incanus*. Information from McMinn (1942), Munz and Keck (1973), and Sampson and Jespersion (1963).

*Ceanothus thyrsiflorus* (blueblossom, fig. 6) occurs in southern Oregon and northern California coastal regions on both forest and chaparral sites. *Ceanothus incanus* (fig. 6) is often associated with coast redwood. It occurs in coast redwood and mixed evergreen forests along the northern California coast.

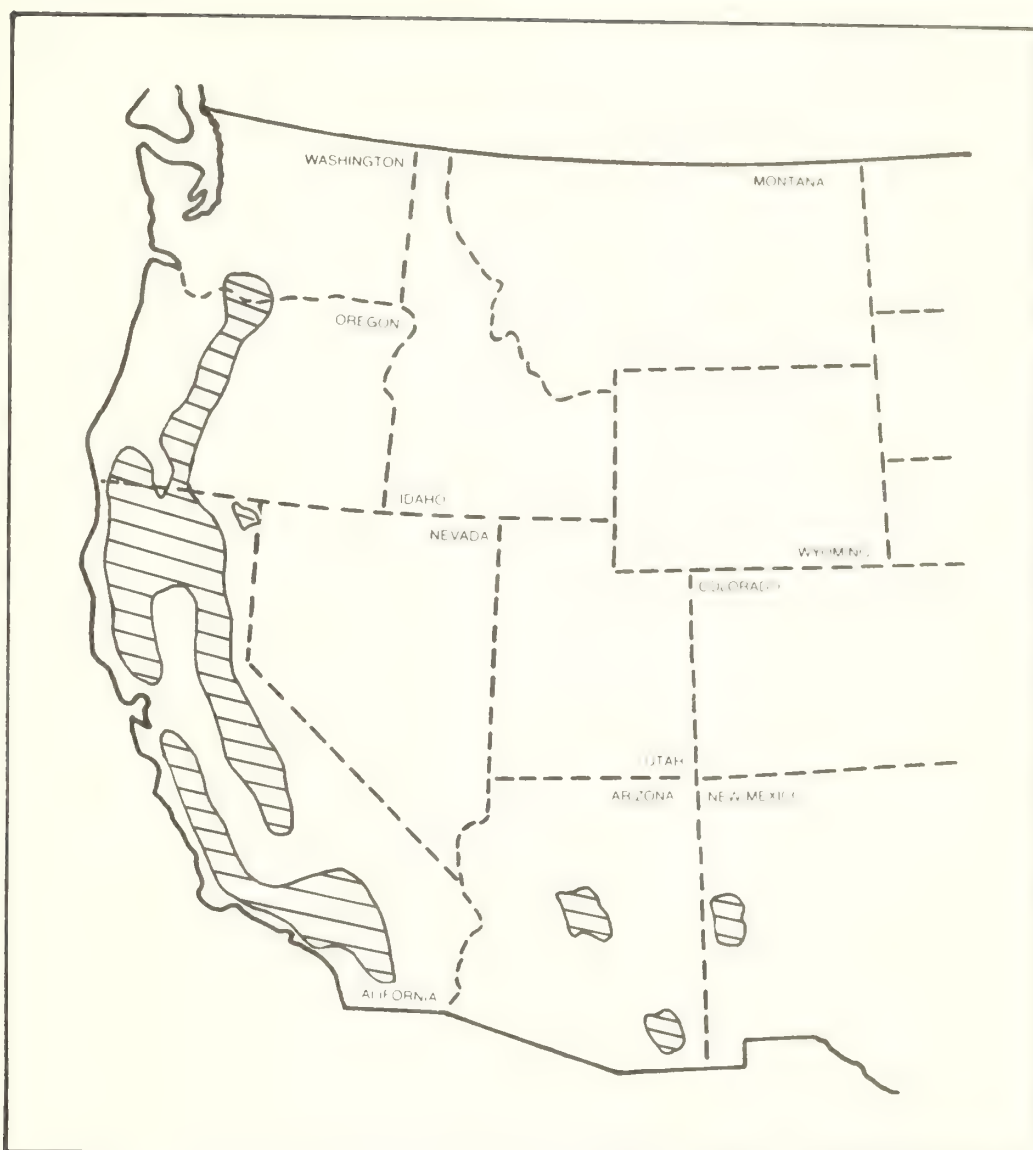


Figure 7.—Distribution of *Ceanothus integrerrimus*. Information from McMinn (1942), Hitchcock and Cronquist (1961), Sampson and Jespersion (1963), and personal observations of the authors.

*Ceanothus integrerrimus* (deerbrush, fig. 7) is widely distributed both geographically and ecologically and occurs from the dry ponderosa pine forests into the western hemlock and white fir zones. It is also associated with Coulter pine at lower elevations in southern California. Gratkowski (1961a) identified *C. integrerrimus* as a major brush species in the Umpqua, Rogue, and Cascade regions of southern Oregon. It is also found in chaparral of the southern Rocky Mountains. Will Moir<sup>2/</sup> notes that this species can occur in chaparral and in riparian forests in Arizona and southwestern New Mexico. Cronmiller (1959) indicates that it can form dense stands, it can sprout, and it can be eliminated with repeated disturbance. According to the Range Plant Handbook (USDA Forest Service 1937), it is "one of the most valuable western browse plants."

<sup>2/</sup> Personal communication, Will Moir, USDA Forest Service, Southwestern Region, Albuquerque, NM 87102.

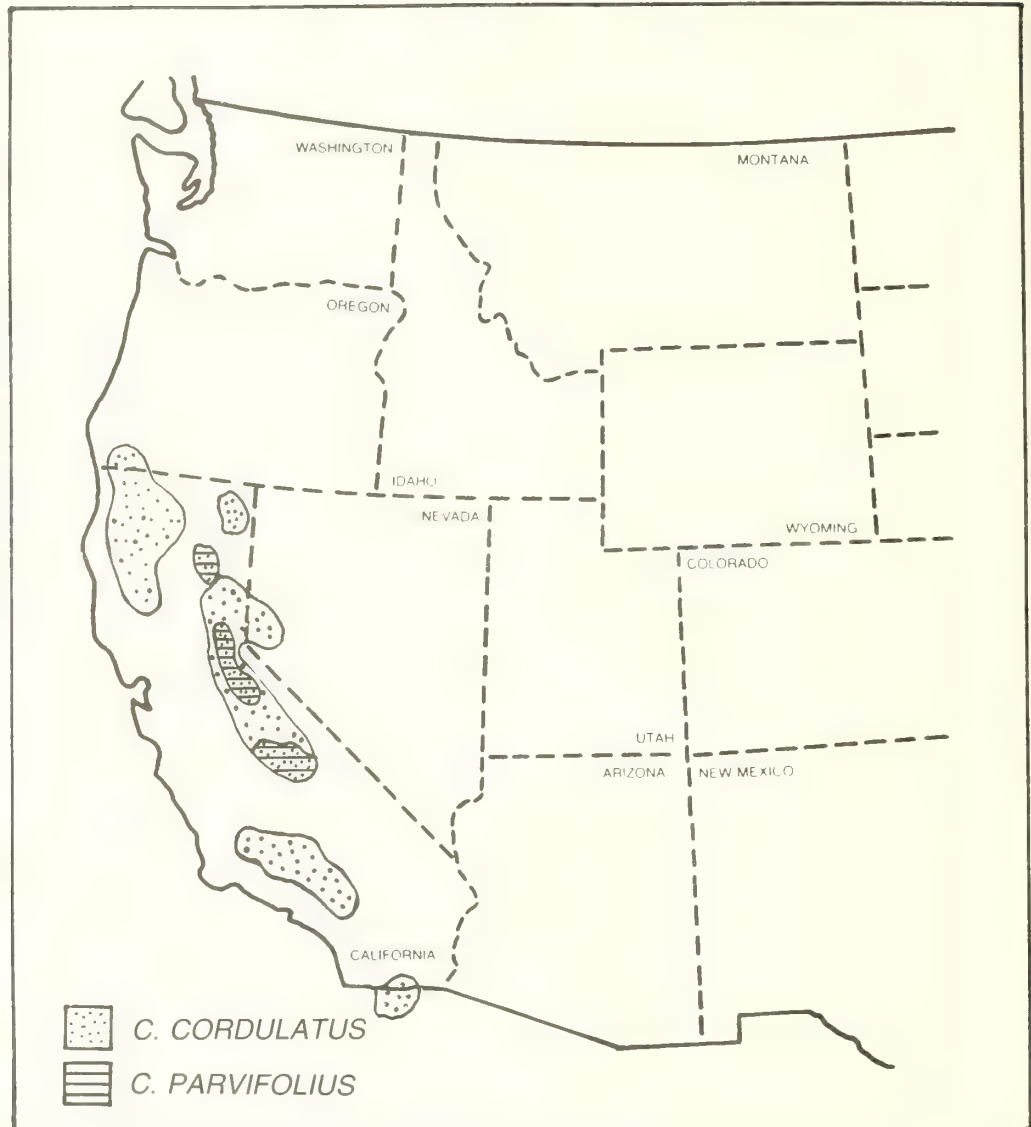


Figure 8.—Distribution of *Ceanothus cordulatus* and *C. parvifolius*. Information from McMinn (1942), and Sampson and Jespersen (1963).

Two California species are *Ceanothus cordulatus* (mountain whitethorn) and *Ceanothus parvifolius* (fig. 8). *C. cordulatus* is widespread geographically; it occurs from southern Oregon to Baja California and ranges from ponderosa pine forests into the red fir zones. Commonly associated with Jeffrey pine and ponderosa pine, this species increases with disturbance and forms very dense and difficult-to-penetrate brushfields. It also is persistent in the open forests on the midslopes of the Sierra Nevada and transverse ranges in California. *C. parvifolius* is similar but it lacks thorns and has a more limited range.



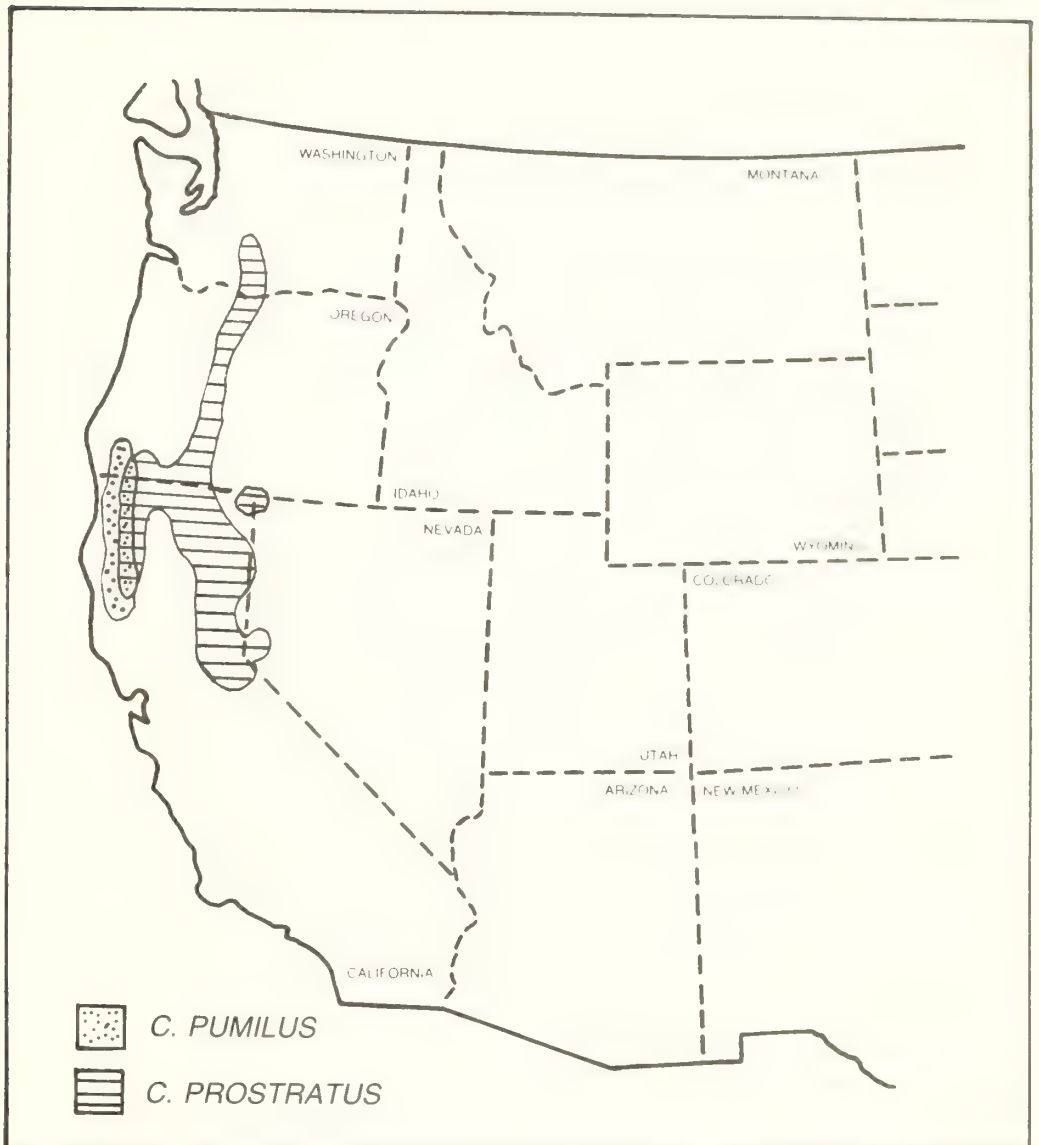


Figure 9.—Distribution of *Ceanothus prostratus* and *C. pumilus*. Based on information from McMinn (1942), Hitchcock and Cronquist (1961), and Munz and Keck (1973).

Two that form mats are *Ceanothus prostratus* (squaw carpet) and *Ceanothus pumilus* (fig. 9). *C. prostratus* has a wide elevational range and occurs on dry, lithosolic sites. It is common in Jeffrey pine and ponderosa pine forests in the southern Cascade Range and in the Sierra Nevada. *C. pumilus* is primarily a serpentine species found in association with Jeffrey pine.

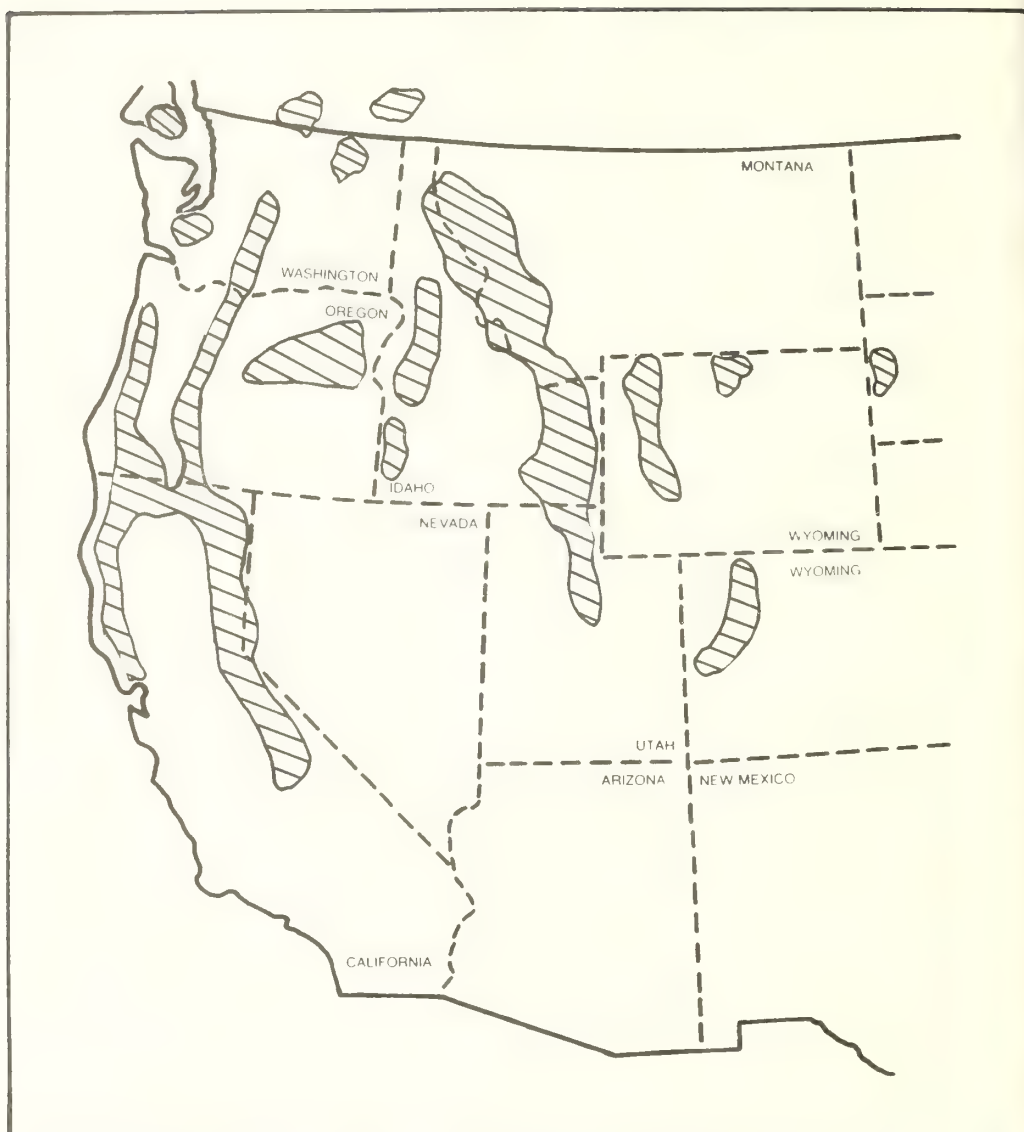


Figure 10.—Distribution of *Ceanothus velutinus*. Information from McMinn (1942), Mueggler and Campbell (1982), and Youngblood and Mueggler (1981).

*Ceanothus velutinus* (fig. 10), one of the most important forest species, has two widespread varieties—snowbrush (var. *velutinus*) and varnishleaf (var. *laevigatus*). *C. velutinus* is widespread geographically and grows in a wide variety of habitats. In California, it occurs in mixed evergreen, red fir, white fir, mixed conifer, Jeffrey pine, and ponderosa pine forests. In Oregon, it is found in mixed conifer, mixed evergreen, western hemlock, and lower Pacific silver fir zones. In the interior Rocky Mountain region, it is found in ponderosa pine, Douglas-fir, mixed conifer, and lower subalpine zones. *C. velutinus* is important in brushfield formation. On sites where it develops best it is seral—a successional species that reproduces through persistent seed that is perhaps three or four centuries old. It is eliminated as a

shrub when the canopy closes. It can persist in mature forests on some sites, however, such as the decomposed granitic habitats in eastern Montana, which belong to the Douglas-fir series.

*Ceanothus velutinus* is the most extensively studied of the forest *Ceanothus* species. The studies include investigations of the ecological role, autecology, role in nitrogen cycling, and competitive abilities of the species. Wahlenberg (1930) investigated the vigor and mortality of ponderosa pine seedlings planted in, at the edge of, or outside *C. velutinus* clumps or bushes. Fire stimulates germination and sprouting but is not absolutely required for *C. velutinus* to reproduce. Halpern's data (unpublished) from the H. J. Andrews Experimental Forest, Willamette National Forest, show that *C. velutinus* may occur on sites that are disturbed but not burned. It develops more rapidly and more completely on sites that are burned, but occasional seeds can germinate on sites that are not burned. *C. sanguineus* is even less dependent on fire than is *C. velutinus* and it can develop into good stands on unburned sites.

## Conclusions

*Ceanothus* species are tolerant of stress but intolerant of shade, are capable of nitrogen fixation, can reproduce from persistent seeds that require heat to germinate, have a limited ability or no ability to sprout, and require moderate disturbance to reproduce.

*Ceanothus* is a very important genus as a food source for wildlife. The Range Plant Handbook (USDA Forest Service 1937) describes *C. sanguineus*, *C. thyrsiflorus*, and *C. fendleri* as being some of the most important browse species in their respective ranges.

*Ceanothus* is important in site amelioration. The genus does have nitrogen-fixing and other soil-building attributes. It is tolerant of severe sites, and it can play a soil-building role on these sites.

*Ceanothus* species, especially those such as *C. prostratus* that form mats, are important in erosion prevention. Several species have root systems that can help to prevent mass soil movements.

*Ceanothus* species (in particular *C. prostratus* and *C. integerrimus*) have been mentioned as nurse crops. In dense *Ceanothus* thickets, however, some species (*C. velutinus*, *C. integerrimus*, *C. cordulatus*, and *C. cuneatus*) are regarded as very strong competitors that can retard the establishment and growth of conifers.

The roles and the controversies surrounding *Ceanothus* species provide several researchable problems. Quantitative data are needed on the actual roles that *Ceanothus* plays on various sites. There is a need for better predictive information on *Ceanothus*. For example, where will *Ceanothus* occur? What role does *Ceanothus* play in nitrogen fixation on a specific site? How serious are *Ceanothus* species as competitors? How important is *Ceanothus* competition over the rotation of a conifer forest? Do the positive contributions made by *Ceanothus* to a forest system offset its competitive impact on conifers?



### 3. Autecology and Synecology of *Ceanothus* <sup>1/</sup>

#### Autecology

#### Seed Production, Germination, and Survival

**Seed production.**—*Ceanothus* species that have been studied appear to be prolific seed-producers. Although no published data are available on the age when seed production begins, field observations indicate that *C. integerrimus* begins to produce seed at about 4 years of age and *C. velutinus* begins seed production after 6 to 10 years in northern California.<sup>2/</sup> Even less information is available for sprouts. Sprouts of *C. velutinus* can produce prolific seed crops 8 years following cutting.<sup>3/</sup> In general, sprouts of most species begin to produce at least some seed after 3 to 6 years.

More is known about numbers of seeds produced. Estimates for various *Ceanothus* species of numbers of seeds stored in the duff range from  $4.6 \times 10^6$  viable seeds per hectare ( $1.9 \times 10^6$ /acre) for *C. cordulatus* and *C. parvifolius* combined in California (Quick 1956) to  $2.5 \times 10^5$  seeds per hectare ( $1 \times 10^5$ /acre) for *C. velutinus* in Oregon (Gratkowski 1962). Three hundred seventy-five thousand germinated seedlings per hectare (150,000/acre) and 150,000 to 600,000 germinated seedlings per hectare (60,000 to 240,000/acre) have been reported for *C. integerrimus* in California (Quick 1956) and *C. sanguineus* in Idaho (Hickey and Leege 1970), respectively.

The generally large seed reservoir in the soil where *Ceanothus* plants are abundant apparently represents only a small percentage of the seed produced annually. Based on 5 years of sampling, seed production by *C. greggii* and *C. leucodermis* on chaparral sites in southern California varied greatly from year to year, with production ranging from 47,000 to  $29.2 \times 10^6$  seeds per hectare (18,800 to  $11.6 \times 10^6$ /acre) for *C. leucodermis* and from 0 to  $170 \times 10^6$  seeds per hectare ( $68 \times 10^6$ /acre) for *C. greggii* (Keeley 1977b). Seed production of mature *Ceanothus* plants may vary greatly from year to year as a function of the carbon stored by plants in the previous year's and the current year's precipitation. In chaparral species, a significant percentage (90 to 99 percent) of the annual seed production is eaten by rodents, with a small percentage consumed by birds and harvester ants.<sup>4/</sup>

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<sup>1/</sup> Participants in this discussion group were: Tom Beebe, Ray Boyd, Paul Dunn, Dick Fredricksen, Charles Halpern, Ed Harshman, Miles Hemstrom, Howard Horowitz, Annabelle Jaramillo, Bruce Kelpsas, Paul Lauterbach, Phil McDonald, Don Minore, Doug Robin, Bob Sanders, Bill Stein, and Howard Weatherly. Discussion Leaders were Tom Atzet and John Tappeiner.

<sup>2/</sup> Personal communication, P. McDonald, Pacific Southwest Forest and Range Experiment Station, 2400 Washington, Avenue, Redding, CA 96001.

<sup>3/</sup> Personal communication, S. Conard.

<sup>4/</sup> Personal communication, R. Quinn, California Polytechnic University, San Luis Obispo, CA 93407.

Conclusions drawn from the discussion of seed production by *Ceanothus* were:

1. In years of high seed production, *Ceanothus* species are capable of producing more seeds in a single year than are stored in the soil.
2. The number of seeds in the soil can be expected to vary from year to year as a function of both seeds produced and seeds utilized by consumers.
3. Substantial seed reservoirs exist in the soil in areas that have been dominated by *Ceanothus* species.

**Seed longevity.**—Seeds of *Ceanothus* species are thought to be long-lived. Gratkowski (1962) reports viable *C. velutinus* seeds in the duff of conifer stands over 200 years old. The only direct information on longevity, however, comes from work by Quick and Quick (1961) who obtained excellent germination in *Ceanothus* seeds known to be 9 to 24 years old. More studies in this area are needed.

**Seed dissemination.**—Because the seeds of *Ceanothus* species are generally small (2-4 millimeters (0.08-0.16 in) long), smooth, hard, and round, they tend to stay where they fall, gradually filtering into the duff and soil, unless they are carried off by small animals (rodents, birds, ants).

When *Ceanothus* seeds ripen, they are forcibly ejected from the pods. One chaparral species, *C. crassifolius*, has been observed to shoot seeds an average of 3 meters (10 ft).<sup>5/</sup>

**Seed germination.**—Laboratory studies of treatments to stimulate germination of *Ceanothus* species were summarized by Reed (1974). The ability of the seeds to remain viable for years under field conditions is a function of a strong seedcoat dormancy. As the seeds dehydrate, their hilar fissures act as one-way valves and prevent moisture from being imbibed. In nature, dormancy is broken when the hilum is fractured (Gratkowski 1962). Fire is the most common agent stimulating germination, although high soil temperatures caused by solar radiation and mechanical abrasion may also be factors. Laboratory studies have shown that either soaking in hot water at 80 to 90 °C (176 to 194 °F) or dipping in boiling water for as little as 10 to 30 seconds to as much as 5 minutes will stimulate germination of many *Ceanothus* species. Various combinations of immersion of seeds in sulfuric acid and soaking them in gibberellin or in thiourea will also stimulate germination. Cold, moist stratification normally increases germination significantly following hot water or other heat treatments (Gratkowski 1973). At least one chaparral species (*C. crassifolius*) averages about 15 percent germination if it is placed in water at 70 °C (160 °F) and left in the same water at room temperature, suggesting that cold stratification is not required for all species. Even in this species, though, germination is enhanced considerably by cold stratification (M. Poth, unpublished data). In dry soils, temperatures of 120 to 140 °C (248 to 284 °F) are normally lethal to *Ceanothus* seeds.

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<sup>5/</sup> Personal communication, P. Dunn, Forest Fire Laboratory, 4955 Canyon Crest Drive, Riverside, CA 92507.

In field situations, autumn slash burnings have produced four times as many *C. sanguineus* germinants as have spring burns, presumably because of the hotter temperatures common in autumn burns and the cold, wet stratification that follows with winter weather. Germination following spring burns is often delayed until the following spring (Leege 1968). On two experimental watersheds in the H. J. Andrews Experimental Forest, Willamette National Forest, in western Oregon, the highest crown covers of both *C. sanguineus* and *C. velutinus* occur in the most heavily burned areas (C. Halpern, unpublished data). Chaparral studies have shown that soil temperatures in hot or moderate fires may reach 150 °C (302 °F)—a lethal temperature—down to 2.5 centimeters (1 in) in dry soils (DeBano and others 1977).

**Seedling survival.**—Although large numbers of seeds of *Ceanothus* species typically germinate after fire, mortality is high, especially in the first few years following germination. For example, in the Sierra Nevada, *C. integerrimus* decreased from 750,000 seedlings per hectare (300,000/acre) in the first year to 25,000 per hectare (10,000/acre) after 10 years; 6,250 (2,500/acre) after 20 years; and less than 1,250 per hectare (500/acre) after 30 years (Cronemiller 1959). Rapid early mortality has also been observed from *C. velutinus*, *C. sanguineus*, *C. cuneatus*, and *C. megacarpus* on some sites. In pure stands, however, densities of these species appear to level off after 5 or 6 years. Density of 5-year-old *C. velutinus* in the mixed species shrub community near Mount Shasta, California, ranges from 2,250 to 3,750 per hectare (900 to 1,500/acre) (P. McDonald, unpublished data). Schlesinger and others (1982) report decreases in *C. megacarpus* seedlings on sites from 101,250 per hectare (40,500/acre) at age 1 to 20,250 per hectare (8,100/acre) at age 20.

Because *Ceanothus* species are generally intolerant of shading, they begin to die out after conifers grow through the shrub canopy (approximately 10 years on some *C. velutinus* sites in Oregon; considerably longer on some sites in the Sierra Nevada). Only a small percentage of the viable seeds in the soil germinate after a typical fire. Because of large numbers of seeds in the soil, even relatively low germination is sufficient to produce high densities of *Ceanothus* shrubs.

## Plant Growth and Stand Development

**Seedlings.**—Both varieties of *C. velutinus* (var. *laevigatus* and var. *velutinus*), as well as other *Ceanothus* species, exhibit sigmoidal height growth. Height growth is slow until age 4 or 5 years in var. *velutinus* and until age 3 years in var. *laevigatus* and then is rapid until about age 10 years when it begins to level off. A typical *C. velutinus* var. *velutinus* stand in Oregon or California reaches a height of 0.6 to 2.5 meters (2 to 8 ft) after 10 years. Stand height sometimes decreases between age 15 and 50 as older stems collapse. Maximum stand height depends on site characteristics. In the Cascade Range (McKenzie Ranger District, Willamette National Forest), the number of *C. velutinus* plants decreased from 3,700 at age 4 years to less than 400 at age 12 years (E. Harshman, unpublished data). The data showed a rapid exponential decline in numbers required for full cover until about age 8 or 9 years, when the decline became more gradual as shrubs approached maximum size. Little site-specific information is available, however. In one study in the northern Sierra Nevada, *C. integerrimus* was reported to grow 7 to 11 centimeters (3 to 4 in) the first year, and 20 (8), 30 (12), and 36 centimeters (14 in) in years 2, 3, and 4, respectively. Total height growth after 5 years ranged from 0.8 to 1.3 meters (2.5 to 4.3 ft). This species begins to spread out rapidly, horizontally and vertically, in the third year (P. McDonald, unpublished data). Cronemiller (1959)



reported similar growth data from the Stanislaus National Forest in the Sierra Nevada. As with *C. velutinus*, growth varies considerably from one site to another.

**Sprouts.**—Although many *Ceanothus* species are vigorous sprouters following top removal, few data are available on the growth rates of sprouting shrubs. Sprout growth of 51 to 65 centimeters (20 to 25 in) after 1 year and 1.0 to 2.1 meters (3 to 7 ft) after 5 years have been observed for *C. velutinus*.<sup>6/</sup> *C. integerrimus* sprouts grew 75 centimeters (30 in) in the first year after burning on one site (Cronemiller 1959). Sprout growth rates also vary from site to site.

The ability to sprout may also be a function of the age and vigor of the plant when cut. In one study in the Cascade Range, when *C. velutinus* plants were cut, the percentage of sprouting plants decreased from 100 percent for 5-year-old plants to 50 percent for 11-year-old plants. Almost no sprouting was observed on 13-year-old plants (R. Sanders, unpublished data). In the Sierra Nevada, however, vigorous sprouting was observed following cutting of 35- to 50-year-old *C. velutinus* (Conard and Radosevich 1982a). Again, these patterns vary from site to site.

**Productivity.**—The interest in *Ceanothus* species as browse for big game has led to several studies of annual stem growth and biomass production. Leege and Hickey (1975) report average annual twig growth for 32- to 36-year-old *C. sanguineus* plants in Idaho ranging from 23.6 to 30.5 centimeters (9.3 to 12 in). Annual growth was significantly correlated with May to August precipitation totals and was higher on south than on east or west aspects. They also observed substantial twig dieback, especially on older plants, during periods of severe winter temperature fluctuations. Winter twig dieback was also reported by Young and others (1948) for *C. sanguineus* in northern Idaho and by Stickney (1965) on *C. velutinus* in Montana. Winter desiccation of foliage is a common occurrence on *C. velutinus* in the Cascade Range in Oregon and in the Sierra Nevada.<sup>7/</sup> Little is known about how this dieback may affect either annual or long-term productivity.

Kie (unpublished data) has recently developed models relating annual production of twigs and foliage by *C. integerrimus* and *C. cordulatus* to measures of shrub volume and to overstory crown closure in the southern Sierra Nevada. Published models are available that relate *C. integerrimus* browse production to stem diameters (Bartolome and Kosco 1982) and *C. cordulatus* browse production to canopy area of shrubs (Eberlein 1982).

**Biomass and nutrient cycling.**—Most available biomass and nutrient cycling data are for *C. velutinus*. This species accumulates biomass rapidly. Martin and others (1981) report aboveground biomass values of 36 metric tons per hectare (16.2 t/acre). Zavitskovski and Newton (1968) and Youngberg and Wollum (1976) report accumulation rates of 4 000-5 000 kilograms per hectare per year (3,560-4,450 lb/acre) for the first 10-15 years with slower rates at later stages. *C. velutinus*

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<sup>6/</sup> Personal observation, S. Conard.

<sup>7/</sup> Personal observation, S. Conard.

biomass is high in nitrogen, and stands older than 10 years may contain more than 500 kilograms per hectare (445 lb/acre) of nitrogen. The forest floor may contain an additional 300 kilograms per hectare (267 lb/acre) of nitrogen. Nitrogen cycling in aboveground litterfall is even more striking. Zavitkovski and Newton (1968) measured an average of 90 kilograms per hectare (80 lb/acre) per year in *C. velutinus* ecosystems. This rate of nitrogen recycling in litterfall exceeds other temperate forest ecosystems except those containing nitrogen-fixing plants such as *Alnus*.

*C. megacarpus* is also a prodigious biomass producer and nitrogen cyclor. Schlesinger and others (1982) recorded biomass accumulation rates of 3 000 kilograms per hectare (2,670 lb/acre) per year over 20 years. A 22-year-old stand contained 480 kilograms per hectare (427 lb/acre) in biomass, 200 kilograms per hectare (178 lb/acre) in the forest floor, and 70 kilograms per hectare (62 lb/ac) in annual litterfall. The values for this chaparral species are similar to those noted previously for montane *C. velutinus* and much greater than average for nonnitrogen-fixing chaparral species.

**Root distribution.**—Root systems of *Ceanothus* vary considerably from species to species. Most species are deep rooted with a large number of fine roots near the soil surface. A species with shallow roots is *C. greggii*, a chaparral species that has over 90 percent of its roots in the top 30 to 40 centimeters (12 to 16 in) of soil (Kummerow and others 1977, Miller and Ng 1977) and a root-to-shoot biomass ratio of 0.25 to 0.39 (Miller and Ng 1977). Roots of *C. greggii* var. *vestitus*, on the other hand, have been found down to 4 meters (13 ft) in chaparral (Hellmers and others 1955). *C. prostratus* roots may extend down to 1.5 meters (5 ft) and may even penetrate the C soil horizon (Tappeiner and Helms 1971).

*C. velutinus* roots extend to depths of 1.8 to 2.4 meters (6 to 8 ft) and extend laterally well past the crown of the plant. In southwestern Oregon, *C. cuneatus* seedlings had roots averaging 20 centimeters (8 in) in length after one growing season (Gratkowski 1961b). Maximum length of roots was reported for *C. leucodermis* in southern California by Hellmers and others (1955). This species had a maximum rooting depth of 6.4 meters (21 ft), and the lateral extent of the roots was approximately 2.3 times that of the aerial parts.

**Longevity.**—Compared to other genera of shrubs, *Ceanothus* are short lived. This may be because these species are eventually shaded out by overtopping vegetation; overtopping begins to occur at 10 to 75 years on sites where conifers are present. Individual 40-year-old plants of *C. velutinus* and *C. integerrimus* have been observed (Cronemiller 1959). In the Sierra Nevada, vigorous *C. velutinus* were still present in a brushfield that had resulted from a fire 50 years earlier (Conard and Radosevich 1982a). In the Cascade Range, however, mature *C. velutinus* are often subjected to heavy injury to root crowns from snow (Zavitkovski and Newton 1968), which can lead to senescence of stands. The functional life span of *C. velutinus* on many sites in the Cascades is believed to be between 20 and 40 years before shading by conifers and snow damage begin to decrease its vigor. Observations in the Rocky Mountains have suggested that periodic fire is necessary to maintain the vigor of *C. sanguineus*. Without fire, plants of *C. sanguineus* may be replaced by other shrub species, such as *Holodiscus* or *Prunus*.

**Table 1--Browse value and protein content of *Ceanothus* foliage**

Species	Browse value <sup>1/</sup>			Crude protein Percent
	Deer	Cattle	Sheep	
<i>C. cordulatus</i>	1-2	4	3	6-15
<i>C. cuneatus</i>	3	4	2-3	8-15
<i>C. integerrimus</i>	1-2	2-3	1-2	12-20
<i>C. prostratus</i>	2-3	5	4-5	5-10
<i>C. thyrsiflorus</i>	2-4	3-4	2-3	--
<i>C. velutinus</i>	3	5	4	up to 17

<sup>1/</sup> Browse value: 5 = useless, 4 = poor, 3 = fair, 2 = good, 1 = excellent.  
Source: Sampson and Jespersen 1963.

**Biotic agents.**—*Ceanothus* foliage, twigs, and seeds are an important food source for wildlife and domestic grazers. The foliage of *Ceanothus* is high in protein and can be an attractive spring and summer forage for deer, elk, cattle, and sheep. Management to favor production of *Ceanothus* for browse is common on big game ranges (Hickey and Leege 1970, Leege 1979). Palatability and protein content of several major *Ceanothus* species that occur in California are summarized in table 1. One species that is heavily browsed by elk and deer is *C. sanguineus*. On five sites in Idaho, 25 to 80 percent of the annual growth was removed by elk (McCulloch 1955); deer use of this species can reach similar levels (Thilenius and Hungerford 1967). *C. sanguineus* and *C. integerrimus* are preferred over *C. velutinus* as browse. Snowshoe hare are also heavy browsers of *Ceanothus sanguineus* on some sites (Asherin 1974). Rodents (with an assist from birds and ants) may eat as much as 99 percent of the annual seed crop of *Ceanothus* on chaparral sites.<sup>8/</sup> Predation could have profound effects on *Ceanothus* establishment after disturbance if similar seed predation occurs on forest sites.

A large number of biotic agents, such as birds, insects, mammals, and fungi, have been shown to affect *Ceanothus* species. Birds often act as seed dispersal agents. Several insect species heavily infest seeds of *Ceanothus* species in some years and can cause substantial loss of viable seeds. Reductions of 9 to 27 percent in seed production were reported for *C. sanguineus* and 80 percent for *C. greggii* following infestations by wasps, weevils, and caterpillars (Bugbee 1971, Furniss and others 1978). The California tortoise shell butterfly can severely defoliate both *C. velutinus* and *C. integerrimus*.<sup>9/ 10/</sup> Although no quantitative data are available, plants seem to recover within a few weeks from severe infestations.

<sup>8/</sup> Personal communication, R. Quinn, California Polytechnic University, San Luis Obispo, CA. 93407

<sup>9/</sup> Personal communication, A. Shapiro, University of California, Davis, CA 95616.

<sup>10/</sup> Personal communication, P. McDonald, Pacific Southwest Forest and Range Experiment Station, 2400 Washington Avenue, Redding, CA 96001.



Fungi may be another important biotic agent that affects *Ceanothus* species on forest sites. *Armillaria mellea* parasitizes *C. velutinus* by girdling roots mechanically with rhizomorphs (Tarry 1968). Because this fungus is not host specific, infections in *Ceanothus* stands could provide a source for attack of conifers growing on the same site. The *Cytosporina* state of the fungus *Eutypa armeniacae* has been reported to cause stem dieback of several *Ceanothus* species (Moller and others 1971a, b).

Effects of some of these biotic agents might be confused with foliage or twig dieback caused by winter injury, as discussed earlier. Additional information on how these biotic agents affect *Ceanothus* species and their associates would be useful to those managing growth and distribution of *Ceanothus* species in forest systems.

## Synecology

*Ceanothus* species occur over a wide geographic area and have a large number of associates in many plant communities. Much of the known information on distribution patterns of individual species was presented earlier. Little quantitative information on productivity, community ecology, and successional relationships of *Ceanothus* species in forest ecosystems is available.

The distribution of sprouting and nonsprouting species of *Ceanothus* appears to be related to frequency of fires. Nonsprouting species are more common than sprouting species, and more sprouting species occur in the Sierra Nevada, where lightning-caused fires are more frequent, than at low elevations. Keeley (1977a) discusses potential evolutionary reasons for these differences.

Information describing forested plant communities in which the major *Ceanothus* species occur has been reported for Oregon and Washington (Franklin and Dyrness 1973), the west side of the Cascade Range in Oregon (Hemstrom and others 1982), northeastern Washington (Daubenmire 1953), Montana (Pfister and others 1977), and California (Barbour and Major 1977).

**Seral status of *Ceanothus* species.**—Although few data on specific seral sequences are available (Conard and Radosevich 1982b), *Ceanothus* species are generally considered pioneers because of their fire-dependent reproductive strategies. Where they are not shaded out by taller shrubs or trees, however, some species can persist as a long-term, semipermanent component of the vegetation. Observations suggest that *C. cuneatus* may form a climax vegetation type on some sites in southwestern Oregon and that *C. velutinus* is part of the climax vegetation in open ponderosa pine woodlands on the east side of the Cascade Range.

*Ceanothus* species as indicators of site productivity for conifers.—Based largely on the field experience of the participants in this session, several relationships between site quality and the species of *Ceanothus* present are suggested and summarized:

<u>Location</u>	<u><i>Ceanothus</i> species according to site quality</u>	
	Best sites (wet)	Worst sites (dry)
Southwestern Oregon	<i>velutinus</i> → <i>integerrimus</i> → <i>prostratus</i> → <i>cuneatus</i> → <i>pumilis</i>	
Idaho	<i>sanguineus</i> → <i>velutinus</i>	
Eastern Washington	<i>velutinus</i> → <i>sanguineus</i>	
Sierra Nevada (California)	<i>diversifolius</i> → <i>integerrimus</i> → <i>prostratus</i> → <i>lemmoni</i> → <i>cuneatus</i>	
Northern California	<i>integerrimus</i> → <i>prostratus</i> → <i>lemmonii</i> → <i>cuneatus</i>	

Intuition has led to different conclusions from one region to another. This discussion group concluded that good information on correlations among distribution of *Ceanothus* species and site quality, moisture availability, and temperature are sorely lacking.

## Research Needs

The following needs were identified for future research on the autecology and synecology of *Ceanothus* species:

1. Quantifying optimum and extreme values of environmental factors such as site quality, elevation, aspect, plant moisture stress, and degree days for growth and establishment of each species of *Ceanothus*.
2. Quantifying interactions among *Ceanothus* species and their associates in the major (forest) plant communities where they occur.
3. Defining the autecological characteristics of individual species. Some of the most critical are: age at onset of seed production (for seedlings and sprouts), longevity of plants, duration of viable seed in the soil, influence of shrub age on sprouting capacity, and rates of shrub growth and canopy development.

## 4. Interactions Between *Ceanothus* Species and the Soil System <sup>1/</sup>

*Ceanothus* is one of the most widespread genera of nodulated, nonleguminous, nitrogen-fixing plants in North America. Many of the nitrogen-fixing species in this genus occur in the western United States and are integral components of forest ecosystems (Youngberg and Wollum 1976, Zavitkovski and Newton 1968). Nitrogen (N) fixation occurs in nodules that range from simple lobes or clusters a few millimeters across, which are white when fresh, to large, brown lobes 21 centimeters (8 in) across (Bond 1963, Furman 1959, Gardner 1976). Fixation of atmospheric dinitrogen ( $N_2$ ) has been reported in the field and confirmed in the laboratory (Delwiche and others 1965, McNabb and Geist 1979, Russell and Evans 1966).

In 1890, Beal described hyphae and swollen structures inside nodules of *Ceanothus*. More recently, Furman (1959) and Kummerow and others (1978a) detail the filamentous nature of the nitrogen-fixing endophyte. Isolation and culture techniques for *Frankia* have been developed (Lalonde 1979), and the endophytes have been isolated and cultured for *C. americanus* by D. Baker and for *C. crassifolius* and *C. oliganthus* by M. Poth.<sup>2/</sup> It is known from microscopic observations and from inferences drawn from cultures of the alder endophyte that the microorganism is filamentous and encapsulated by a host membrane (Lalonde and Knowles 1975). The filaments terminate in swollen tips or vesicles that appear to be the site of  $N_2$  fixation (Kummerow and others 1978a).

Although all *Ceanothus* species tested to date are capable of fixing  $N_2$  if a suitable inoculum of the endophyte is present (Delwiche and others 1965), little is known about host-specificity and environmental influences. In the field, both the degree of nodulation and the rate of  $N_2$  fixation (or accretion) vary greatly among species and among sites (McNabb and Geist 1979, Youngberg and Wollum 1971). Possible causes for these observed variations include inherent differences among species of host and endophyte, physical and biological site factors, environmental conditions, and variability in assessment and measurement methods and research designs.

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<sup>1/</sup> Participants in this discussion group were: Ray Armstrong, Dick Fredricksen, Martin Jurgensen, Logan Norris, Dan Binkley, John Marshall, Dave McNabb, Dave Perry, Harold Evans, Bill Schlesinger, and Jim Boyle. The discussion leaders were Sharon Rose and Kermit Cromack.

<sup>2/</sup> Personal communication, M. Poth, Forest Fire Laboratory, 4955 Canyon Crest Drive, Riverside, CA 92507.



**Factors Affecting Nodulation and N<sub>2</sub> Fixation.**--Chemical, physical, and biological characteristics of the soil will affect both the infectivity and effectiveness of the N<sub>2</sub>-fixing endophyte and will influence the rate of N<sub>2</sub> fixation.

High levels of ammonium nitrogen in the soil decrease N<sub>2</sub>-fixation rates of *C. velutinus* in laboratory conditions (Rodriguez-Barrueco and others 1970), but this has not yet been tested experimentally in the field. The suppression of N<sub>2</sub> fixation by high soil N levels is widespread in both the legumes and other families of N<sub>2</sub>-fixing host plants (Rodriguez-Barrueco and others 1970). Other macronutrients known to influence nodulation and N<sub>2</sub> fixation in *C. velutinus* include calcium, phosphorus, and sulfur (Scott 1973). Evidence for the broad applicability of these results to other *Ceanothus* species comes from work on free-living microorganisms and legumes. Calcium is required by most free-living N<sub>2</sub>-fixing microorganisms and is essential for fixation in leguminous hosts.<sup>3/</sup> A deficiency in phosphorus may inhibit nodulation, and a low soil pH has been shown to decrease the effectiveness of the legume endophyte (see footnote 3). The micronutrients molybdenum, cobalt, and nickel are necessary for N<sub>2</sub> fixation in legumes and may be required as well by nonleguminous plants (Silvester 1977). Nickel is essential for the synthesis of hydrogenase in *Rhizobium japonicum* and presumably is required for this enzyme to function in nonleguminous plants (see footnote 3). High levels of aluminum and manganese may be toxic to either the endophyte or host.

Environmental extremes may influence both the endophyte and the host and will directly affect N<sub>2</sub> fixation. Variables such as soil temperature, soil moisture, and light affect physiological processes in *C. velutinus* (McNabb and Cromack 1983, Wollum and Youngberg 1969). Soil temperature affects both the number and size of nodules formed on *C. velutinus* (Wollum and Youngberg 1969). Nitrogen-fixation rates in *C. velutinus* can decrease following decreases in soil temperature, soil moisture, and light (McNabb and Cromack 1983). Kummerow and others (1978a) found fewer healthy nodules on *Ceanothus* plants when the soil was dry than when the soil was moist. Wollum and Youngberg (1969) found maximum nodulation on *C. velutinus* when the soil temperature was 23-26 °C (73-79 °F).

Age of seedlings, site preparation, and disturbance also affect nodulation and N<sub>2</sub> fixation. Kummerow and others (1978a) found nodules on only 4 of 100 6- to 8-month-old *Ceanothus tomentosus* seedlings that had germinated following a fire in the Tecate Mountains, although they did find nodules consistently on 5- to 10-year-old shrubs of *C. greggii*. Youngberg (1966), however, notes maximum nodulation following logging and burning, provided the age of the timber is 100 years or less. He attributes high nodulation to increased light intensity on the site following logging and to heat scarification of *Ceanothus* seeds by fire. He also hypothesizes that poor nodulation on older sites could result from a lack of the endophyte when a site had been dominated by conifers for many years. Nodulation and the general health of the plants declined after several years, probably because of canopy closure and the intolerance of *Ceanothus* to shade.

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<sup>3/</sup> Personal communication, H. Evans, Botany Department, Oregon State University, Corvallis, OR 97331.

Photosynthates produced by the host and transported to the roots supply the necessary carbohydrates to the nodular endophyte (Paul and Kucy 1981). Rodriguez-Barrueco and others (1970) suggest that when N is added to the soil in the form of fertilizer, the host plant grows faster and utilizes surplus carbohydrates, thus denying a carbon supply to the endophyte and reducing N<sub>2</sub> fixation. Youngberg (1966) states that *C. velutinus* produces less photosynthate under shade conditions and, consequently, has fewer nodules and lower N<sub>2</sub> fixation.

Soil chemistry, including such factors as cation exchange capacity, base saturation, organic matter content, and ion concentrations, influences the endophyte as it lives in the soil and directly influences the growth of the host plant and degree of nodulation (Scott 1973). White (1967) notes an absence of nodules on *C. cuneatus* roots in plants growing in serpentine soil. This may be because of ion imbalance, especially of calcium, magnesium, nickel, and chromium. It is not known if the ions affect the populations of the endophyte or the actual nodulation process.

Nodulated *Ceanothus* plants are also commonly mycorrhizal. It has been demonstrated that when legumes are mycorrhizal there is an increase in nodulation and N<sub>2</sub> fixation (Carling and others 1978). Rose and Youngberg (1981) found a similar synergism in *C. velutinus*. Nodulated *Ceanothus* with mycorrhizal fungal partners produced three times more nodular tissue and fixed about twice as much N<sub>2</sub> per plant as did nodulated plants without mycorrhizae. Increased N<sub>2</sub> fixation both in legumes and actinorhizal plants is attributed to increased nutrient uptake and healthier plants producing more photosynthates than nonmycorrhizal nodulated plants (Carling and others 1978, Gardner and others 1984, Rose and Youngberg 1981).

## Methods for Measuring N<sub>2</sub> Fixation

The methods for measuring N<sub>2</sub> fixation in both the field and laboratory include acetylene reduction, natural isotope (<sup>15</sup>N) tracer studies, isotope (<sup>15</sup>N) enrichment studies, N-accretion studies, and analysis of N-transport products in xylem sap. Each of these methods has a bias and built-in assumptions that may or may not be valid for an individual study and may account for much of the variation in reported N<sub>2</sub>-fixation rates and N accumulation.

Sources of errors in determining N<sub>2</sub>-fixation rates arise from taking too few samples and from making wide extrapolations from one sample at one time. The difficulty of estimating nodule biomass accurately, seasonal variations in nodule biomass, short-term variations in nodule efficiency and activity (due to changing environmental conditions), and differences among sites add to the problem of accurately quantifying N<sub>2</sub>-fixation rates.

Rates of N<sub>2</sub> fixation vary by *Ceanothus* species, site, age of the plants, season, and light regime (McNabb and Cromack 1983, McNabb and Geist 1979). Some of the rates of N<sub>2</sub> fixation (or accretion) that have been estimated in field studies are summarized in table 1.

The participants in this session discussed at length the most important methods for measuring N<sub>2</sub> fixation and changes in soil N levels in laboratory and field studies. This discussion focused on the appropriate or potential uses, the assumptions required for drawing conclusions, and the potential sources of error for each method. A brief description of each method and a summary of the points brought up in the discussions follow:

**Table 1--Estimated rates of N accretion or N<sub>2</sub> fixation on forest and chaparral sites in the Western United States**

<i>Ceanothus</i> species and location	Accretion or fixation	Stand age	Source	Method
	kg/ha/yr	years		
<i>Ceanothus velutinus</i> , H. J. Andrews Experimental Forest, Oregon	<sup>1/</sup> 42-48 <sup>2/</sup> 95-100	0 and 12	Binkley and others 1982	chronosequence
<i>C. velutinus</i> , H. J. Andrews Experimental Forest, Oregon	<sup>3/</sup> 101	17	McNabb & Cromack 1983	acetylene reduction
<i>C. velutinus</i> , Cascade Range, Oregon	<sup>1/</sup> 56 <sup>2/</sup> 84	0-15	Youngberg and others 1979	accretion
<i>C. velutinus</i> , Cascade Range, Oregon	<sup>1/ 4/</sup> < 0-40 <sup>1/ 4/</sup> < 0-46 (96)	2-33	Binkley unpublished data, Zavitkovski and Newton 1968	chronosequence; accretion
<i>C. velutinus</i> , Cascade Range, Oregon	<sup>2/</sup> 72-108	0-10	Youngberg and Wollum 1976	accretion
<i>C. sanguineus</i> , Vancouver Island, British Columbia	<sup>1/</sup> 24-50 <sup>2/</sup> 45-80	10	Binkley and Husted 1983	accretion, based on spatial variation
<i>C. greggii</i> var. <i>perplexans</i> , San Diego County, California	<sup>3/</sup> 0.1	25	Kummerow and others 1978	acetylene reduction
<i>C. crassifolius</i> , San Dimas Experimental Forest, Southern California	<sup>1/</sup> 28 <sup>2/</sup> 76	0-13	Zinke 1969	accretion

<sup>1/</sup> Soil N accretion.

<sup>2/</sup> Ecosystem N accretion (soil, litter, biomass).

<sup>3/</sup> N<sub>2</sub> fixation in field.

<sup>4/</sup> Highest number is average over first 10 years.



**1. Acetylene reduction.**—In the acetylene reduction method, nodule tissue is incubated in an acetylene-enriched atmosphere, and the amount of ethylene evolved is assayed as an indirect measure of nitrogenase activity in the nodules (Postgate 1972). The efficiency of the reduction reaction may sometimes be considerably less than the theoretical ratio of 0.3 moles of N production for each mole of ethylene evolved (Bergersen 1980, Hardy and others 1968). Additional sources of error occur when this method is used to estimate seasonal or annual  $N_2$ -fixation rates per unit area in the field. To develop reasonable estimates using this approach, investigators need estimates of the current age, structure, and vigor of the stand. By measuring levels of environmental regulating factors such as light and moisture in the field, laboratory data on responses of fixation (acetylene reduction) to environmental conditions can be incorporated into these models.

**2. Accretion.**—Estimates of soil N accretion over time can be made by successive measurements of soil N levels on one or more sites (Youngberg and Wollum 1976) or in experimental plots in stands of pure species composition (Zinke 1969). Many years are obviously required to obtain meaningful results with this approach, and the accuracy of estimates relies heavily on the accuracy of initial estimates of N pools and soil N.

**3. Chronosequence.**—Another method for studying accumulation of soil N over time is to measure the soil N levels on sites with a range of ages following the establishment of *Ceanothus* (Binkley and others 1982, Zavitzovski and Newton 1968). In this approach, the assumptions must be made that (1) baseline levels of soil N are the same on all sites and (2) historical patterns of  $N_2$  fixation have been the same on all sites. Even if sites are selected very carefully, differences in site characteristics (such as micronutrient levels) and in patterns of vegetation development or of nodulation are likely to make these assumptions questionable. Violation of these two assumptions can introduce substantial error into estimates of N accumulation made by this method.

It is important, furthermore, to recognize that both chronosequence and accretion studies yield only estimates of changes in soil N levels over time, not rates of current or past  $N_2$  fixation. These methods do not generally take into account N losses caused by plant uptake, leaching, and denitrification, nor do they allow compartmentalization of input sources such as rainfall, lightning, and nitrification. Therefore, estimates of N balance made by these methods do not represent fixation rates unless corrections can be made for other inputs and outputs of N in the ecosystem. If inputs and outputs can be quantified independently these methods might allow  $N_2$  fixation to be estimated with reasonable accuracy.

**4. Natural isotope distribution.**—In most soils, the ratio of  $^{15}N$  to  $^{14}N$  is higher than it is in the atmosphere. The basis for the natural isotope discrimination method for estimating  $N_2$  fixation is that the ratio of these isotopes in plant tissues should reflect the source of the plant's N. A plant that obtains most of its nitrogen through nodular fixation of  $N_2$  therefore, has a ratio close to that in the atmosphere, whereas plants that do not fix  $N_2$  have ratios closer to that in the soil. Theoretically, the ratio,  $^{15}N:^{14}N$  (expressed commonly as atom percent excess of  $^{15}N$ ), can be partitioned to yield an estimate of what proportion of a plant's N has been derived from the atmosphere (Bergersen 1980, Delwiche and others 1979, Silvester 1983).

This method permits the investigator to follow N through an ecosystem or through a plant. A potential problem with this approach is that the within-pool variation in various ecosystem components (such as soil and plant tissue) may be high enough to make detection of differences among species, among ecosystem components, or among treatments difficult. The advantages of this method for ecosystem studies are that it gives integrated values of  $N_2$  fixation over time, it can be used where nodules are difficult to locate or to excavate, and measurements are made on easily obtained materials (leaves, stems, soil). The method has been used successfully to estimate  $N_2$  fixation by mesquite and other species in desert ecosystems (Shearer and others 1983) and to detect differences in the atom percent excess of  $^{15}N$  between presumed  $N_2$ -fixing and nonfixing plants in a wide range of northern California ecosystems (Virginia and Delwiche 1982).

**5.  $^{15}N$  isotope enrichment.**—In this method, the nodules or roots are placed in an atmosphere that has been enriched in known amounts with  $^{15}N_2$  (Bergersen 1980, Silvester 1983). The atom percent excess of  $^{15}N$  in the samples (plants, nodules, roots) following treatment can provide an estimate of the amount of  $N_2$  fixed during the incubation period and (for whole plants) of the distribution and biochemical fate of that N within the plant. This method allows direct comparisons to be made among fixing and nonfixing plants. Disadvantages include the high costs of isotopic N and of chemical analysis. The same problems of high within-pool variability that were discussed before can occur, especially in field studies, and laboratory studies require disturbance of living plant material as well as its monitoring in a somewhat unnatural environment. Despite potential shortcomings, this technique has provided extremely useful information in a large number of studies. It was used by Delwiche and others (1965) to estimate rates of  $N_2$  fixation for 12 *Ceanothus* species that occur on forest and chaparral sites in California.

**6. Xylem sap.**—In both legumes and nonlegumes, certain N-transport compounds found in the xylem serve primarily as carriers for symbiotically fixed N, while other compounds are carriers for N obtained from the soil solution (Dixon and Wheeler 1983, Pate 1980). In soybeans, for example, the abundance of ureides (relative to that of nitrate-N) in xylem sap decreased from 94 percent to 9 percent as the proportion of plant N derived from  $N_2$  fixation decreased from 100 percent to 1 percent (Herridge 1982). In this same study, a positive relationship was apparent between the concentration of ureides in the xylem and the rate of  $N_2$  fixation measured by acetylene reduction. The major transport compounds for symbiotically fixed nitrogen are species specific (Pate 1980). Citrulline appears to dominate in alder and asparagine in *Ceanothus* (Dixon and Wheeler 1983). Relationships could theoretically be determined between rates of  $N_2$  fixation and concentrations of N-transport compounds in the xylem by obtaining independent estimates of  $N_2$  fixation using acetylene reduction or  $^{15}N$  enrichment techniques. Although this approach is still in the early stages of development, it shows particular promise for studies of deep-rooted woody species such as *Ceanothus*, because it has potential for permitting  $N_2$  fixation to be estimated without access to the rooting zone of the plants.

Additional details, and a wealth of references, on methods of evaluating  $N_2$  fixation can be found in Bergersen (1980) and in Silvester (1983).

## Research Needs

The following needs for future research on interaction between *Ceanothus* species and the soil system were identified:

1. Identify the factors that influence nodule establishment and development.
  - a. Determine factors that influence the presence and efficacy of the endophyte.
  - b. Quantify the influence of microenvironmental parameters (such as water, light, temperature).
  - c. Quantify the influence of soil chemistry characteristics, such as soil pH, calcium, and micronutrient levels.
2. Identify the factors that limit N<sub>2</sub>-fixation rates.
  - a. Determine the importance of genotypic variability of hosts and endophytes.
  - b. Measure effects of factors such as soil moisture, soil temperature, plant moisture stress, light, and photosynthetic rates.
3. Identify the factors that affect N-cycling rates.
  - a. Determine whether or not non-N<sub>2</sub>-fixing plants cycle as much N in litterfall as do plants that fix N<sub>2</sub>.
  - b. Determine the importance of abiotic factors and site characteristics in regulating N cycling.
  - c. Determine the influence of *Ceanothus* on pathways and rates of N cycling.
4. Quantify the changes in soil organic matter that accompany N accretion, and determine the effects of soil organic matter on soil moisture infiltration, moisture retention, soil aggregation, soil aeration, and overall soil structure.
5. Investigate litter decomposition patterns.
  - a. Quantify rates.
  - b. Determine the roles of microorganisms and of macrofauna, such as earthworms, in these patterns.



## 5. Physiological Ecology of *Ceanothus* and Associated Conifer Species<sup>1/</sup>

The presence of *Ceanothus* on a site can affect many aspects of the conifer growth environment other than nitrogen availability and nutrient cycling. Effects of *Ceanothus* on environmental factors—such as light, water, and temperature—as well as production of allelopathic substances can potentially affect the growth and survival of associated conifers. The relative abilities of conifers and *Ceanothus* species to exploit resources and to tolerate resource depletion are determining factors in dynamic interactions in the vegetation. This section considers effects of *Ceanothus* on environmental factors, effects of environmental conditions on conifers and *Ceanothus* species, and the implications of these effects for shrub-conifer interactions.

### Effects of *Ceanothus* on the Conifer Growth Environment

**Light.**—Many *Ceanothus* species have dense canopies. Few data are available, however, on the actual light levels under *Ceanothus* canopies. Petersen (1980) used ozalid paper and measured 30 percent of full sunlight (integrated over the whole day) at the bottom of the live canopy in 5- to 10-year-old *C. velutinus* stands in the Cascade Range. Conard and Radosевич (1982a) report 7 percent of full sunlight at midday at the soil surface under 35- and 50-year-old *C. velutinus* in the Sierra Nevada. McPherson and Muller (1967) used a hand-held light meter to find values of 200 to 4,000 foot-candles under *C. cuneatus* canopies in Santa Barbara County, California.

**Soil temperature.**—Soil-surface temperatures in summer under *C. velutinus* canopies in the Cascade Range were 11 to 33 °C (20 to 60 °F) lower than temperatures in adjacent unshaded areas (Scott 1969, Youngberg 1966). The average soil-surface temperatures in August as measured in open areas by Scott (1969) frequently exceeded 65 °C (150 °F). Temperatures this high have been reported to cause substantial seedling mortality in many conifer species (Hare 1961, Silen 1960) and could be expected to inhibit survival of natural germinants in unshaded microsites.

Midsummer soil temperatures at the 15- and 45-centimeter (6- to 18-in) depths in areas where *C. velutinus* and *Arctostaphylos patula* had been removed were generally 1 to 4 °C (1.8 to 7.2 °F) higher than temperatures where the shrubs had not been removed (S. Conard, unpublished data). Mean temperatures in late July at the 15-centimeter (6-in) depth in this study were 17 °C (63 °F) in the open and 15 °C (60 °F) under the canopy.

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<sup>1/</sup> Participants in this discussion group were: Ned Dimock, Iwend Holen, Denis Lavender, Bill Lopushinsky, Dave McNabb, Pete Owston, Terry Petersen, Greg Prull, Steven Radosевич, Bob Tinnin, Bob Wagner, Jack Walstad, and Diane White. The discussion leader was Susan Conard.

Although high soil-surface temperatures may inhibit survival of conifer germinants, there is no evidence that they have negative effects on planted seedlings. Two potential benefits to conifers from slightly higher temperatures in the rooting zone are that root growth could begin earlier in the spring in open areas and that higher soil temperature could enhance the ability of roots to remove water from the soil. These benefits could be compounded by the soil where shrubs have been removed having substantially more soil moisture below the top 15 centimeters (6 in) than the soil where shrubs are present.

Little or no information is available on the influence of other *Ceanothus* species on soil temperatures or on the relative ecological importance of small differences in rooting-zone temperature on conifer growth. Without additional research, it is impossible to determine the ecological importance of small temperature differences in the rooting zone of planted or naturally established conifers. Routine installation of thermocouples or thermistors in experiments measuring soil moisture with moisture blocks could provide a great deal of soil temperature information at low cost.

**Air temperature.**—Conard and Radosevich (1982a) observed higher air temperatures inside live *Ceanothus* canopies than in open areas. They consistently observed minimum temperatures 2 to 3 °C (3 to 5 °F) lower and maximum temperatures 2 to 3 °C (3 to 5 °F) higher under a *C. velutinus* canopy than at the same height outside the canopy or at the same height (50 cm; 20 in) in the open. This relationship is probably a function of reradiation from stems and a lack of air mixing within the canopy. The relationship is probably dependent on canopy structure and would not be expected to be true for all species of *Ceanothus*. Further research is needed to: (1) determine how common these effects are within shrub canopies, (2) evaluate the effects of factors such as time of year and aspect, and (3) determine what influence (if any) such temperature differences might have on conifer growth or survival.

**Soil moisture.**—Several studies have measured soil moisture under *C. velutinus* canopies and compared it to soil moisture in areas where shrubs were removed or where shrubs were absent. Soil moisture in the top 15 centimeters (6 in) remained higher throughout the season under *C. velutinus* canopies than in the open (Scott 1969, Youngberg 1966). In these studies, however, "open" areas had dense covers of grasses and other herbaceous vegetation that typically have shallow rooting systems as compared to shrub species. Petersen (1980) created open areas in *C. velutinus* brushfields by removing shrubs and herbaceous vegetation with herbicides. In his study, soil moisture at 10 centimeters (4 in) was depleted more rapidly by shrubs than by herbaceous vegetation on one site. On another site, soil moisture depletion by shrubs and herbaceous vegetation at 10 centimeters was comparable. At 40 centimeters (16 in), shrubs depleted soil moisture more rapidly than did herbs on both sites. On one site, soil water potentials under herbaceous vegetation reached a minimum of about -8 bars for the season; water potentials under shrubs had decreased to less than -15 bars by late July. At 100 centimeters (39 in), soil water potential stayed greater than about -2 bars under herbaceous vegetation and was decreased to -15 bars by mid-July to mid-August where shrubs were present. Soil moisture showed no seasonal decrease at any depth where measurements were made if both shrubs and herbs were controlled.

Conard and Radosevich (1982a) report similar responses in soil moisture levels under *C. velutinus* canopies and in treatments where shrubs were removed in the Sierra Nevada. Scott (1969) also reports substantially lower minimum soil water potentials under *C. velutinus* (about -12 bars) than in the open under herbaceous vegetation (about -8 bars) at a 70-centimeter (24-in) depth. *C. prostratus* has also been shown to deplete soil moisture to approximately -15 bars by late summer at depths from near the surface to 45 centimeters (18 in) (Tappeiner and Helms 1971).

Although specific information on many *Ceanothus* species is lacking, the data presented above for *C. velutinus* and *C. prostratus* suggest that these species growing on forest sites can decrease soil water potentials to near -15 bars by late summer in the rooting zone of young conifers. Comparisons with areas where *Ceanothus* is not present must be made carefully as results can vary widely depending on what other vegetation is present on the site or on whether soil conditions in areas being sampled are comparable.

**Humidity.**—The presence of transpiring *Ceanothus* crowns causes substantial local increases in humidity and decreases in wind velocity. The net result of these effects is a decrease in evaporative demand. Conard and Radosevich (1982a) and Petersen (1980) document 120- to 180-percent increases in evaporation rates (measured with Piché evaporimeters) on *C. velutinus* sites when either shrubs or shrubs and herbs had been removed. The participants were aware of no similar studies on other *Ceanothus* species.

**Allelopathy.**—Tinnin and Kirkpatrick (in press) evaluate the allelopathic potential of water extracts of recent litterfall from several important shrub species in southwestern Oregon. In laboratory bioassays, *C. integrerrimus* and *C. velutinus* reduced growth of *Cucurbita* by 30 percent and 60 percent, respectively. *Ceanothus velutinus* extracts also reduced root elongation of Douglas-fir germinants. Experiments in natural soils are in progress. Conard (1985) found that water extracts of fresh *C. velutinus* foliage also cause significant inhibition of radicle elongation in white fir germinants.

Rose and others (1983) found that water-soluble extracts of *C. velutinus* litter had varied effects on the growth of several mycorrhizal fungi that are found on conifers. All concentrations (parts per thousand, per hundred, per ten) stimulated the growth of *Cenococcum geophilum*. High concentrations (parts per ten) of extract inhibited the growth of *Laccaria laccata*. *C. velutinus* litter leachate also reduced mycorrhizal formation on Douglas-fir seedlings.

No studies to date have demonstrated the allelopathic effects of *Ceanothus* species on conifers in the field. Because of the observed effects on root growth and mycorrhizal formation in laboratory studies, allelopathy might be expected to be most important in situations where water or minerals are limiting and where the inhibition of root elongation significantly decreases efficiency of water or mineral uptake.



## Effects of Environmental Conditions on Conifer Growth

The effects of *Ceanothus* on conifer growth are a function of how well the conifers are able to establish, survive, and grow under the modified environmental conditions established by *Ceanothus* and of how well the conifers can compete for potentially limiting resources such as light and water.

Factors that can affect growth of conifer species include the photosynthetic surface area of individual plants and the photosynthetic efficiency of the tissues. Under potentially limiting environmental conditions, responses of photosynthesis to light, temperature, and water availability can greatly influence seasonal growth in the field. Relative growth rates can provide valuable information about responses to different environmental conditions.

**Light.**—Although most conifers do not require full sunlight for maximum photosynthesis of individual branches or of seedlings, the light saturation level of a mature tree can vary considerably as a function of crown structure. Most pine species, however, require close to full sunlight for maximum photosynthesis. Light requirements that have been reported for maximum photosynthesis of conifers range from about 2,000 to 2,500 foot-candles ( $\sim 400$  to  $500 \mu\text{E m}^{-2} \text{sec}^{-1}$ ) for seedlings of Douglas-fir and western hemlock (Brix 1967, Krueger and Ferrell 1965, Krueger and Ruth 1969). In contrast, light saturation is around  $1\,000 \mu\text{E m}^{-2} \text{sec}^{-1}$  for individual fascicles of ponderosa pine (Coyne and Bingham 1982), and 3,500 and  $>9,500$  foot-candles (about 700 and  $>1\,900 \mu\text{E m}^{-2} \text{sec}^{-1}$ ), respectively, for needles and seedlings of loblolly pine (Kramer and Kozlowski 1979).

Minimum light requirements for establishment and survival are considerably lower, although little quantitative information is available (Atzet and Waring 1970). Light requirements may be particularly important when the requirements of the conifer species differ from those of associated noncrop species with which they are competing. For example, Conard and Radosovich (1981) found that white fir reached 90 percent of maximum photosynthesis at  $0.53 \text{ mmol m}^{-2} \text{sec}^{-1}$  ( $1 \text{ mmol} = 10^3 \mu\text{E}$ ), compared with  $0.71 \text{ mmol m}^{-2} \text{sec}^{-1}$  for *Ceanothus velutinus*. This difference in light requirements fits in well with the ability of white fir to survive under the shrub canopy and eventually to overtop and shade out the *Ceanothus*.

Several authors (Baker 1949, Minore 1979, Waring 1970) have ranked the shade tolerance of conifers. Of the western conifers, western hemlock and western redcedar are among the most shade tolerant, most true firs are intermediate, and pines have relatively low shade tolerance. Despite ranges in tolerance (ability to survive and grow at low light levels), both greenhouse and field studies suggest that growth of a wide range of conifer species increases with increasing light up to 70 to 100 percent of full sunlight. Species studied in the field (Emmingham and Waring 1973) have included Douglas-fir, white fir, and red fir.

With field studies it is difficult to separate effects of light level on photosynthesis and growth from effects of factors such as water availability. In greenhouse studies on Douglas-fir, incense-cedar, Port-Orford-cedar, ponderosa pine, Jeffrey pine, Monterey pine, and tamarack, only growth of Port-Orford-cedar, Jeffrey pine, and Douglas-fir showed clear evidence of light saturation—at about 65 to 70 percent of full sun (Baker 1945).

It is frequently difficult to extrapolate lab results to field situations where adaptations of foliage to light may vary and environmental factors such as temperature and water stress may limit photosynthesis. Even under field conditions where light may be expected to limit photosynthesis, other limiting factors may be more important. For example, increasing available soil moisture may stimulate photosynthesis and growth, while increasing light availability may have little or no effect if water remains limiting. In terms of management, the *most* limiting factor or factors must be identified and ameliorated for a substantial growth response to occur. In the absence of other limiting factors, however, we would expect conifer saplings to show significant increases in growth anytime light is increased from low levels (less than 50 percent full sun) to almost full sunlight.

The light levels a seedling has experienced previously will also precondition it and will affect its response to manipulation of light intensity. Reduced light decreases canopy volume and vigor and alters the structure, photosynthetic efficiency, and responses of the photosynthetic apparatus and stomata to low light intensities. Because of these changes, suppressed conifers may require a period of adaptation following sudden exposure to full sun, primarily because shade leaves have poorer ability to control water loss than do sun leaves. Sudden exposure may result in mortality, nearly total loss of current needles, or severe reduction in height and diameter growth for one or more years. Plants that survive can be expected to recover once a full complement of sun-adapted foliage is developed. Responses of this type have been observed for western hemlock (Keller and Tregunna 1976), white fir (Conard and Radosevich 1982a), and Douglas-fir (Petersen 1980). The severity of exposure shock will vary among species and within species among habitats. Assuming that exposed plants survive, then long-term growth response to overstory removal should be positive.

The decreased radiation load and higher relative humidity under shrub canopies appear to aid the establishment of seedling conifers in both *C. prostratus* (Tappeiner and Helms 1971) and *C. cordulatus* (S. Radosevich, unpublished data). Based on the effects of *C. velutinus* on evaporative demand and light intensity, similar factors might explain differences in natural seedling densities of Douglas-fir that have been observed under and outside *C. velutinus* canopies (See section 5 for additional detail on these studies).

**Soil moisture.**—Both field and laboratory studies have shown that soil water potentials between -1 and -5 bars are sufficient to limit photosynthesis in many conifer species (Havranek and Benecke 1978, Zavitkovski and Ferrell 1970). In a laboratory study of five western conifers (Lopushinsky and Klock 1974), transpiration rates decreased to 50 percent of maximum at soil water potentials ranging from -4 to -8 bars. At -10 bars, transpiration rates of grand fir and ponderosa pine were about 35 and 12 percent of maximum values, respectively. At high vapor pressure deficits between leaf and air, stomata will close at even higher soil water potentials than indicated by these studies.

Because *Ceanothus* species can decrease soil moisture to below these levels by midsummer, conifers growing with *Ceanothus* can be expected to have transpiration and photosynthesis rates below their potential maxima for some of the growing season on many sites. Low soil and plant water potentials would also be expected to reduce conifer root growth.



## Physiological Responses of *Ceanothus* Species to Environmental Conditions

In general, *Ceanothus* species maintain high stomatal conductances and high photosynthesis rates at substantially lower plant and soil water potentials than do associated conifers. Photosynthesis rates of *C. integerrimus*, *C. cordulatus*, and *C. velutinus* were near their seasonal maxima at plant water potentials at least as low as -25 to -30 bars, -24 bars, and -20 bars, respectively, in a study in the central Sierra Nevada (Lanini 1980). Conard and Radosevich (1981) found that photosynthesis and leaf conductance of *C. velutinus* remain at maximum rates even in late summer at the lowest plant water potentials observed (-18 bars). Other studies (Marshall and Waring 1984) have found that *C. velutinus* in the Oregon Cascade Range has extremely high stomatal conductances and poor stomatal control. Stomatal closure has been reported to occur at leaf water potentials of -30 and -20 bars for *C. thyrsiflorus* and *C. incanus*, respectively (Barnes 1981). These species all occur in forest habitats. For *Ceanothus* species of drier chaparral habitats, tolerance to low water potentials may be even greater. Stomatal closure has been reported at water potentials of -55, -45, and -55 to -60 bars for *C. ferrisae*, *C. ramulosus*, and *C. greggii*, respectively (Barnes 1981, Poole and Miller 1975).

*Ceanothus* species in general are capable of maintaining high photosynthesis and transpiration rates under conditions when photosynthesis of conifers will be severely limited. This is demonstrated by Conard and Radosevich (1981) for *C. velutinus* growing with white fir in the Sierra Nevada. Copeland (1932) estimates that *C. velutinus* and *C. cordulatus* in the northern Sierra Nevada transpire approximately 0.6 meters (2 ft) of water per unit leaf area over the growing season. He estimates that transpiration of *Castanopsis sempervirens*, *Quercus vaccinifolia*, and *Q. kelloggii* was about half that of the two *Ceanothus* species. *Ceanothus* species also have a high light requirement for maximum growth (Schlesinger and others 1982) and photosynthesis (Conard and Radosevich 1981). This characteristic might be expected for early seral species.

**Conclusions.**—*Ceanothus* species can decrease light intensities to levels well below those required for maximum growth of conifers. Thus, one would expect reduced growth of conifers under *Ceanothus* canopies even in the absence of other limiting factors. On many sites where *Ceanothus* and conifers are growing together, however, soil moisture depletion is probably the major factor limiting conifer photosynthesis except, perhaps, during the early part of the growing season. *Ceanothus* may have a competitive advantage because it can absorb water from relatively dry soil. In spite of high internal water stress, *Ceanothus* can maintain open stomata and continue photosynthesis. Conifers are less able to do so. The result is that *Ceanothus* species have the potential to compete strongly with conifers and to reduce conifer growth.

Levitt (1980) suggests that at high stress, users tend to revert to conserver strategies. It appears that stress levels in forest systems are rarely high enough to induce this for *Ceanothus*. Even if it does occur, little benefit could be expected to accrue to the less tolerant conifers.

The potential benefits to conifers from N<sub>2</sub> fixation by *Ceanothus* species are discussed in section 4. These and other benefits (such as amelioration in seedling environment and improved wildlife habitats) will need to be balanced against potential growth losses in making management decisions. The duration of conifer growth suppression could vary widely from site to site depending how long it takes for conifers to achieve dominance and begin to suppress associated *Ceanothus*.



## Research Needs

This discussion group identified 12 areas where further research is needed:

1. Effects of canopy structure of different *Ceanothus* species on environmental factors such as light penetration, soil and air temperatures, humidity, and surface soil moisture need to be determined, and influences of season, aspect, and slope need further study.
2. Descriptions are needed of the development over time of vertical and horizontal structure of *Ceanothus* canopies (individual shrubs and communities) including biomass and leaf area.
3. Patterns of light distribution under canopies need to be quantified using techniques such as fisheye lens photography, quantum (PAR) sensors, or correlations with canopy structure, biomass, leaf area, and canopy volumes.
4. Studies are required on the effects of light levels, such as those found under *Ceanothus* canopies, on the productivity of conifers at various stages of community development.
5. Importance of the allelopathic potential of *Ceanothus* species in field situations, including the influence on conifer growth and rates of  $N_2$  fixation, should be investigated further.
6. Effects of environmental modification by *Ceanothus* species on their own ability to fix  $N_2$  need to be quantified. There is some evidence that dense stands of *C. velutinus* may reduce soil moisture to levels that inhibit symbiotic  $N_2$  fixation. This topic was discussed in more detail in section 4. Effects of canopy structure and distribution on factors such as soil temperature might also be important here.
7. Correlations should be developed that would permit information on photosynthesis and plant water potential of *Ceanothus* species to be used to estimate or predict  $N_2$ -fixation rates under varying environmental conditions.
8. More information is needed on water utilization by both *Ceanothus* and conifer species and on distribution of roots horizontally and by depth. Seasonal patterns of water use at different depths can provide a better understanding of the degree of synchrony of water demands by shrubs and conifers and how this affects the intensity of competition. Better information on root distribution could aid greatly in interpreting studies that are concerned with soil moisture depletion, plant-water relations, and shrub-conifer interactions.
9. Relationships need to be established between canopy volume, biomass, leaf area, and spatial distribution of *Ceanothus* species and their effects on soil moisture regimes.
10. More field data are needed on relationships between environmental moisture deficit, plant moisture stress, photosynthesis, and productivity for conifer species, including effects of water stress in the field on the initiation of conifer dormancy. Information on young planted seedlings of the major commercial species would be particularly beneficial when combined with information from items 1, 2, and 9.

11. Additional research is needed on the relative strength of interspecific competition between *Ceanothus* and conifer species and intraspecific competition among conifers in various situations. These topics are discussed more thoroughly in section 6.

12. A great deal of research relevant to the physiological ecology of *Ceanothus* species in forest habitats has centered on *C. velutinus*. More information on other common forest species such as *C. integerrimus*, *C. cordulatus*, *C. prostratus*, *C. sanguineus*, and *C. thyrsiflorus* would be extremely valuable.

## 6. Effects of *Ceanothus* on Forest Productivity and Conifer Growth<sup>1/</sup>

### Effects of *Ceanothus* on Conifer Establishment

In many ways, this discussion was the focus of the workshop. The discussion provided a forum for integrating some of the basic information presented at earlier sessions, and studies that have attempted to quantify responses of conifers in relation to the presence of *Ceanothus* species were discussed. The major topics were the effects of *Ceanothus* on (1) conifer establishment, (2) early growth of conifers, and (3) site quality.

Several studies have documented better initial establishment of conifer species under *Ceanothus* canopies than in the open. Scott (1969) reports 53-percent stocking of Douglas-fir in *C. velutinus* clumps in the Cascade Range in Oregon, as compared to 36-percent stocking in open areas on the same site. Dyrness and Youngberg (1966), working in an area where canopy coverage of *C. velutinus* was 33 percent, found that 66 percent of the ponderosa pine seedlings on the site are associated with *Ceanothus* clumps. Tappeiner and Helms (1971) report better survival of Douglas-fir and white fir natural regeneration in *C. prostratus* mats than in several other microsites in the Sierra Nevada; Lanini (unpublished data) observed improved survival of planted ponderosa pine, sugar pine, and Douglas-fir seedlings in association with *C. cordulatus* and other shrub species. Show (1924) also reports improved survival of planted ponderosa pine, sugar pine, and giant sequoia as shading by brush increased (in mixed brushfields containing *Ceanothus velutinus*, *Arctostaphylos patula*, and *Castanopsis sempervirens*). Show concludes that the benefits of shading are greatest on poor sites, in dry years, and with small planting stock. Wahlenberg (1930) reports first season survival of 89 percent for planted ponderosa pine under *C. velutinus* canopies and 53 percent in the open in the Rocky Mountains in Montana. He attributes this, in part, to higher humidity, lower evaporative demand, cooler soil temperatures, and higher surface soil moisture under the shrub canopies.

<sup>1/</sup> All workshop participants were members of this discussion group. Discussion leader was Bill Stein.

In the only experimental study we are aware of, Zavitkovski and others (1969) planted seedlings of four conifer species under live *C. velutinus*, under dead *C. velutinus*, in openings, and on freshly burned areas. All species survived best in freshly burned areas. Survival in the other three treatments was equal for ponderosa pine and Douglas-fir. Western hemlock had its lowest survival in openings, and noble fir survival was lowest under live and dead *Ceanothus*. Clearly, different species can be expected to respond differently to the presence of *Ceanothus*. These studies suggest that where *Ceanothus* benefits conifer survival, results may apply both to natural regeneration and to planted seedlings.

Causes for the observed effects of *Ceanothus* species on initial survival may vary. As discussed in a previous section, summer soil temperatures and evaporative demand are frequently lower under *Ceanothus* canopies than in the open. There is also evidence that surface soil moisture remains higher underneath the canopy than where *Ceanothus* is absent (herbaceous vegetation is usually present in the latter areas). These factors are discussed more fully in section 5. Shrubs may provide protection from browsing on some sites, although there have also been reports of increased rabbit damage under *Ceanothus* canopies (Zavitkovski and others 1969). Most reports discussed in this section were based on sample measurements rather than on controlled experiments, so causal relationships can only be postulated. Effects of brush on survival may be confounded in some of these studies with microsite differences between areas where shrubs established initially and areas where shrub establishment was poor ("open" areas).

There is a lack of studies in which the effects of *Ceanothus* on the conifer environment have been specifically characterized and isolated from possible confounding factors. Some of the factors that need to be considered in design of research on this topic are:

1. Effects of different levels (densities, sizes, cover) of *Ceanothus* need to be evaluated on comparable microsites. This requires a replicated, randomized design where levels of *Ceanothus* are manipulated experimentally.
2. Animal damage and other sources of injury (for example, frost and winter desiccation) should be documented.
3. Mechanical damage, such as that from snow, wind, or falling debris, should be documented if it occurs.

## Effects of *Ceanothus* on Early Growth of Conifers

There are two categories of research that have been conducted on the effect of *Ceanothus* on early growth of conifers. The first involved studies in which the structure of *Ceanothus* stands was manipulated experimentally. The second group of studies measured conifer growth relative to varying levels or ages of naturally established, undisturbed *Ceanothus*. These two types of studies were further divided into those dealing with planted conifers and those concerned with natural regeneration.



## Experimental Studies

Several studies have demonstrated dramatic increases in height, diameter, and volume growth of conifers following release from *C. velutinus*. One of the earliest (Gratkowski and Lauterbach 1974) shows 6-year height growth in Douglas-fir to be 170 to 255 percent that of untreated controls following aerial spraying of *C. velutinus* var. *laevigatus*. Petersen and Newton (1982) measured 3-year responses of 5- and 10-year-old Douglas-fir following control of *C. velutinus* or of both *Ceanothus* and herbaceous vegetation. Volume growth of 5-year-old trees was 258 and 415 percent of controls, respectively, where shrubs only or shrubs and herbs were controlled. Results for 10-year-old trees were similar but less striking. Differences among treatments in the study by Petersen and Newton were still accelerating as of the last measurements.

Studies by Weyerhaeuser Company in the Cascade Range in Oregon demonstrated similar increases in height and diameter growth following release of Douglas-fir from *C. velutinus* (Lauterbach 1967). Conard and Radosevich (1982a) report increases of 140 to 200 percent in white fir height growth relative to untreated controls 4 years after release from *C. velutinus*. The largest growth response was observed when shrubs were controlled and the conifers were artificially shaded for several years. Substantial growth check was observed in many released trees that were not shaded. Eight-year cumulative height growth of released trees in the Conard and Radosevich study is 200 percent of controls, and growth of released trees is continuing to increase faster than growth of the untreated controls (S. Conard, unpublished data). Sanders (unpublished data) also reported greater height growth for unreleased trees than for released trees 1 year after manual release from *C. velutinus*. By the second year, released trees on 6 out of 7 sites were growing at prerelease rates, and after 4 years, released trees on all sites were growing significantly better than unreleased trees.

In a study evaluating release of lodgepole pine from *Ceanothus*, no growth response was observed 2 years after treatment (R. Boyd, unpublished data). Other studies have shown, however, that growth reduction can occur for 1 or 2 years following treatment, so a delayed response may well occur.

Only one study was discussed in which effects of site preparation methods on growth of planted conifer seedlings are evaluated. This was a study described earlier, where Zavitkovski and others (1969) planted seedlings in four site preparation treatments. For all four conifer species planted in these experiments, height growth was reduced if the species were planted in *C. velutinus* stands over 10 years old. This corresponds to the age at which *C. velutinus* achieves maximum biomass. Based on 2-year height growth measurements, the effects of other treatments were inconclusive, except that ponderosa pine height growth was highest in fresh clearcuttings.

Height growth of naturally established seedlings was substantially greater in the fresh clearcutting than under live *C. velutinus*; growth increases were 44 percent, 66 percent, 116 percent, and 124 percent for western hemlock, Douglas-fir, ponderosa pine, and noble fir, respectively (Zavitkovski and others 1969). These values suggest that planted seedlings may experience planting check for the first two seasons following planting. It is unfortunate that longer term data are not available for these study sites. Height and diameter growth measurements on conifers 5 and 10 years following treatments could provide valuable information.

The participants were aware of several current research projects in which effects of *Ceanothus* species on survival or growth of conifers are being investigated:

1. A series of administrative studies by the USDA Forest Service in California, Idaho, and Oregon are comparing effects of various chemical and manual site preparation and release treatments on conifer growth, and survival and vegetation development on sites where *Ceanothus* species occur. The principal scientists are W. Stein and E. Dimock II, Pacific Northwest Forest and Range Experiment Station; P. McDonald, Pacific Southwest Forest and Range Experiment Station; and R. Boyd, Intermountain Forest and Range Experiment Station.
2. An intensive study is being conducted through Oregon State University in the H.J. Andrews Experimental Forest, Willamette National Forest, to investigate the long-term effects of *C. velutinus*, at several densities, on conifer growth and on soil properties. This research is being conducted by P. Sollins, Oregon State University.
3. A comparison of several release treatments on *C. velutinus*-dominated sites in western Idaho is being conducted through the Coordinated Research on Alternative Forestry Techniques and Systems (CRAFTS) program under the direction of S. Radosevich, Oregon State University.
4. Several studies on conifer release have been started by scientists at Weyerhaeuser Company, Champion International, and Groundwork, Inc.

## Sampling Studies

Several researchers have reported greater height growth of young Douglas-fir under or at the edge of *C. velutinus* canopies than in open areas between shrubs (Horowitz 1980, 1982; R. Sanders, unpublished data; Scott 1969). The most dramatic results are those of Scott (1969), who reports Douglas-fir heights after 9 years of 1.6, 1.2, and 0.8 meters (5.2, 3.9, 2.6 ft) under shrub canopies, at the edge of canopies, and in the open, respectively. Horowitz (1980, 1982) conducted a similar study on sites with *C. velutinus* in the hemlock and true fir zones in the Cascade Range. He reports slightly to significantly greater height growth by Douglas-fir in edge positions than by those either inside or outside shrub canopies on 60 percent of his hemlock-zone study sites. Growth was greatest in the outside position on 30 percent of the study sites. In the true fir zone, where *C. velutinus* was less abundant, conifer height growth decreased 40 percent from outside to inside shrub canopies, and growth in the edge position was intermediate. In this study, no correlation was observed between shrub cover and conifer growth.

Horowitz (1982) measured conifer and shrub growth on forest sites proposed for aerial release treatments of 2,4,5-T in the Willamette National Forest. Mean crop tree growth was not significantly correlated with the presence or absence of shrub species, although mean growth was correlated with site factors such as elevation and aspect. Five years after herbicide treatment of some of the sites, measurements of crop tree height, leader length, and diameter were not significantly different from those on comparable untreated sites (Horowitz, unpublished data).

Although these studies provide information on the relative growth of conifers in natural situations with and without *Ceanothus*, they do not address the question of how conifer growth might be affected by reduction or removal of *Ceanothus*. Many factors, other than the direct influence of *Ceanothus* on growth, may influence



results in nonmanipulative studies such as these and make results difficult to interpret. The open environment may be particularly stressful for young conifers if they are growing within the active rooting zone of shrubs, or if water-using herbs are present. In addition, shrub regeneration may have occurred preferentially in favorable microsites, and confounding factors such as increased or decreased animal damage in shrub canopies can influence results.

## Effects of *Ceanothus* on Site Quality

Much of the information available on this topic has already been discussed in section 4 so will not be repeated here. There have been few direct measurements of the effect on associated conifers of nitrogen added to the soil by *Ceanothus* species. Youngberg and others (1979), however, report significantly higher levels of foliar N in July in Douglas-fir seedlings growing under *C. velutinus* (1.56 percent N) than in seedlings growing in the open (1.15 percent N) or at the edge of *Ceanothus* canopies (1.32 percent N). They consider 1.2 percent N in foliage to be the minimum for "adequate growth."

A recent study by Binkley and Husted (1983) reports similar results for seedlings associated with *C. sanguineus*. In that study, foliar N levels correlated well with levels of available N in the soil. Binkley and Husted also found higher levels of calcium and magnesium both under the shrub canopies and in the foliage of Douglas-fir growing under the canopies as compared to areas where *Ceanothus* was absent. These studies suggest that, at least on some sites, the presence of *Ceanothus* species can improve the mineral nutrition of associated conifers. Information is lacking on how these differences may affect growth and on what types of sites we can expect to show these types of responses.

There are many areas in the Cascade Range where soil N levels are quite high and rainfall input of N is probably on the order of 2 to 3 kilograms per hectare (2.7 lb/acre) per year. Although this adds up to a large amount of N over several hundred years, it is probably insufficient to maintain long-term productivity with short rotations and frequent slash fires.

## Conclusion

Several general observations came out of this session. First, we do not have sufficient data to permit accurate predictions of the effect that management of *Ceanothus* species will have on long-term site productivity, even for sites where *C. velutinus* is dominant. There is considerably less information on other *Ceanothus* species. Second, we have a poor understanding of the tradeoffs involved in controlling *Ceanothus*. Can reduced conifer growth attributed to competition from *Ceanothus* be balanced by long-term nutritional benefits? Although this is a reasonable hypothesis, it has not yet been tested thoroughly. Because of the effects of water stress on N<sub>2</sub> fixation, that maximum (or near maximum) levels of nutrient addition might be achieved at well below maximum cover of *Ceanothus*. Third, both sampling and experimental studies can add to the understanding of *Ceanothus*-conifer interactions. Whenever possible, information from sampling studies should be verified by well-designed experimental studies. Fourth, the *Ceanothus*-conifer systems are extremely complex: Researchers should be aware of this and avoid simplistic, single-factor interpretations.



## Research Needs

It was generally agreed that many of the past studies on effects of *Ceanothus* species on conifer growth have serious flaws that should be corrected wherever possible in future research. Some of the major recommendations of participants in this regard were:

1. Studies should be designed to avoid confounding of factors such as microsite differences.
2. Sufficient time should be allowed for responses to occur before publication of results. Because of initial growth check following planting or resulting from release treatments, growth responses may not be observed until 3 to 5 years after treatment on many sites. Studies should be designed with at least a 5- to 10-year time frame.
3. Height and diameter measurements should be standard practice. Diameter growth frequently responds more rapidly to treatments than height growth. Furthermore, factors such as shading and moisture stress can alter height-to-diameter relationships dramatically.
4. Effects of treatments on shrub growth, distribution, and canopy volume should also be evaluated. This information is critical for comparing results of different studies, for developing models to predict growth benefits, and to determine where and when these benefits can be expected.
5. Close attention should be paid to the quality and source of planting stock and to careful handling and planting of seedlings.
6. Clear distinction should be made between studies evaluating responses of natural regeneration and those involving planted seedlings.
7. Effects of factors such as animal damage, insect infestation, mechanical damage, and frost injury should be recorded and quantified. For example, in a recent manipulative study in *C. velutinus* brushfields, Perry<sup>2/</sup> observed substantial aphid infestations on Douglas-fir saplings when surrounding shrubs were removed.

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<sup>2/</sup> Personal communication, D. Perry, Forest Science Department, Oregon State University, Corvallis, OR 97331.

## 7. Research Priorities<sup>1/</sup>

Six major areas of needed research were identified: (1) autecology and physiological ecology of *Ceanothus* species, (2) interactions between *Ceanothus* and conifers, (3) development of computer simulation models, (4) synthesis of information that can be obtained from stand sampling, (5) interactions between *Ceanothus* and wildlife, and (6) standardization of study methods and nomenclature. Technology transfer is also needed. Research in the first two areas was ranked as high priority by all three study groups. The importance of summarizing pertinent research information in forms useful to land managers was also discussed, and suggestions were made for implementation. In all research areas, participants stressed the need to obtain more information (1) on species other than *C. velutinus* and (2) from geographic areas outside the Pacific Northwest. There was also general concern expressed over the need for well-designed, replicated studies that can serve multiple purposes. There is a need for long-term studies that will produce information concerning conclusions about the effects of *Ceanothus* over one or more rotations.

### Autecology and physiological ecology of *Ceanothus* species:

1. Investigate requirements for and effects of *Ceanothus* establishment—seed longevity, dormancy, germination requirements, effects of fire intensity, seed production and storage, planting of *Ceanothus*, reproductive strategies (seed vs. sprout), and effects of age, size, and site characteristics on sprouting.
2. Study productivity—determine growth rates, biomass production, site occupancy, canopy structure and densities, seasonal growth patterns (phenology), carbon balance and allocation patterns, and develop predictive models.
3. Conduct detailed field research on nitrogen dynamics—nutrient cycling, nitrogen fixation, and effects of environmental conditions (water, light, temperature, biotic interactions, micronutrients, and pH) and of endophyte characteristics.
4. Conduct field investigations of patterns of water use and water relations of *Ceanothus* species, especially for species other than *C. velutinus*.
5. Investigate effects of *Ceanothus* on erosion prevention and slope stability.

### Interactions between *Ceanothus* and conifers:

1. Identify existing long-term studies (at least 20 years) with adequate design or controls to permit comparisons of sites where *Ceanothus* is present with those where it has been removed. This could provide preliminary estimates of the long-term effects of potential management strategies for *Ceanothus*-conifer systems.

<sup>1/</sup> Participants were divided into three separate groups to identify research priorities. This section summarizes the conclusions of all three groups.

2. Establish long-term experiments to look at effects of absolute and relative densities of *Ceanothus* and conifers on growth, nutrients, and other factors. Both replacement series and Nelder designs are approaches that might be useful. Weigh positive and negative interactions (nitrogen fixation, browse value, moisture competition, and shading).
3. Initiate well-designed studies to evaluate positive and negative effects of release in plantations where *Ceanothus* is well established (for example, codominant or dominant).
4. Investigate interactions between conifers and vegetation that replace *Ceanothus* where *Ceanothus* is controlled. Look at effects of manipulation on seral sequences. Weigh benefits against negative interactions.
5. Investigate effects of timing on interactions; for example, how does the effect of a short rotation of *Ceanothus* followed by its removal and planting of conifers compare with the effect of growing the two species concurrently or eliminating *Ceanothus* entirely?
6. Monitor nutrients, physiology, and environmental conditions in the studies listed above.

#### Development of computer simulation models:

1. Test and integrate scientific concepts or assumptions and generate hypotheses.
2. Evaluate the importance of individual factors that influence interactions between *Ceanothus* species and conifers, such as competition for site resources, growth enhancement, or suppression.
3. Predict responses of *Ceanothus*-conifer association to individual factors, such as nitrogen fixation/accretion, site fertility, and management practices.
4. Facilitate information exchange and stimulate discussion among scientists, land managers, and others.

#### Synthesis of information from stand sampling:

1. Analyze existing stand examination data from a wide geographical area for possible use in acquiring site-specific information.
2. Integrate biological research data with stand examination data for possible use in management of the *Ceanothus*-conifer complex.
3. Corroborate research results on a broader scale.

#### The use of *Ceanothus* species by wildlife:

1. Develop guidelines for wildlife management where *Ceanothus* is abundant.
2. Conduct additional research on wildlife/*Ceanothus* interactions.



3. Investigate the effect of shelter, alternate food, and browse for wildlife on conifer establishment, survival, and growth.

Standardization of study methods and definitions:

1. Define terms and concepts for uniformity; for example, definitions of conifer suppression can incorporate such factors as the percentage of foliage that is above the photosynthetic compensation point (more practically, the percentage of foliage that is shaded), conifer development over a specific period of time, and height of conifer leaders.
2. Develop standardized, statistically sound study methods and designs that will allow comparison of results among experiments.
3. Develop interim guidelines for *Ceanothus* management based on current knowledge of the importance of *Ceanothus* as browse for game species, as a site stabilizer, as a nitrogen fixer, and as a competitor.

Technology transfer:

1. Publish a periodic newsletter describing current studies or research results. This can include a directory of individuals active in *Ceanothus* research and management. Encourage researchers to use existing periodicals (such as Forestry Research West, FIR Report, Forestry Update) for disseminating research information.
2. Develop monograph or book on the biology of *Ceanothus*.
3. Develop a comprehensive manual on the management of *Ceanothus* much like the silvics manual used by foresters.

Many of the research needs that are identified here overlap considerably, and with careful research design and coordination among researchers in different areas, information on many of these topics can be obtained from single experiments. Because of the large investment in time and energy required for large-scale field experiments, the consensus was that coordinated interdisciplinary efforts should be encouraged wherever possible.

## 8. Concluding Remarks<sup>1/</sup>

Much scientifically and operationally useful information is known about *Ceanothus*. Everything about all 55 species in all conceivable environments will never be known. Thus, we must make an investment decision, or rather two:

1. What do we do with the information we have?
2. What new information should we seek, if any?

The answer to the first question is straightforward. The results of this workshop should not only be packaged into a proceedings, but distilled into a "how to" publication for people interested in managing or studying *Ceanothus*. This publication should be presented as widely as audience demand will allow. Thus, we could be reasonably sure what we know about *Ceanothus* will be used and not misused.

The answer to second question is trickier. If we invest in *Ceanothus*, we will not invest in some other dollar equivalent research. Consideration of what we are willing to give up to learn more about *Ceanothus* is a potential problem in obtaining financial support for *Ceanothus* research. I am willing to hypothesize that until we know something about true fir autecology, for example, or how to grow Douglas-fir on specific sites or to meet specific objectives, further research on *Ceanothus* should be defined by two criteria:

1. What hypotheses, leading to results generalizable beyond the genus *Ceanothus*, can be tested most efficiently using *Ceanothus* as a guinea pig?
2. What missing practical information about *Ceanothus* now prevents us from making effective and efficient management decisions?

By way of examples, more than concrete suggestions, I put forward two hypotheses for addressing the first criterion.

1. The general hypothesis that endophyte quantity and quality limit nodulation might be efficiently tested with *Ceanothus*. Nodulation in *Ceanothus* is spotty, but apparently ubiquitous. Testing will require several activities including isolation of the endophyte into pure culture and field experiments where endophyte populations are deliberately manipulated. Neither will be easy.
2. A second general hypothesis is that nitrogen-fixing species employ different evolutionary strategies in the occupation of territory than do nonnitrogen-fixing species. Comparisons of *Ceanothus* with similar but non-nodulating genera could shed light on this question.

<sup>1/</sup> This section prepared by John Gordon, Dean, School of Forestry, Yale University, New Haven, CT 06520.

To address the second criterion, additional practical information should be sought. Ideally, sensitivity analyses should be done to indicate returns from different kinds of environmental information such as that done for soils by Schöne (1983). Because it is unlikely that this will happen, I suggest:

1. Examine the consequences of control by observing the effects of complete and partial control over time on all values of management interest, including wildlife, soil erosion, and crop tree growth, in relation to probable future management systems.
2. Learn how nitrogen accretion occurs; the major need is to know relationships between the quantity and effectiveness of nodules and aboveground variables such as species composition and stem basal area.
3. Learn how variability at the species level can be used for specific management purposes through common garden studies that relate nitrogen fixation to growth rates and competitive effects.

By far, the highest priority for incremental effort is to capture, and to render usable by managers, the results of the last 2-1/2 days.

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## Appendix 1: Scientific Names of Species Cited

### Ceanothus Species

*Ceanothus americanus* L. (New Jersey Tea)  
*C. cordulatus* Kell. (mountain whitethorn)  
*C. crassifolius* Torr. (hoaryleaf ceanothus)  
*C. cuneatus* (Hook.) Nutt. (buckbrush)  
*C. diversifolius* Kell. (trailing ceanothus)  
*C. fendleri* Gray (Fendler ceanothus)  
*C. greggii* Gray (desert ceanothus)  
*C. greggii* var. *perplexans* (Trel.) Jeps.  
*C. greggii* var. *vestitus* (Greene) McMinn  
*C. incanus* T. & G. (coast whitethorn)  
*C. integerrimus* H. & A. (deerbrush)  
*C. lemmonii* Parry (Lemmon ceanothus)  
*C. leucodermis* Greene. (chaparral whitethorn)  
*C. megacarpus* Nutt. (bigpod ceanothus)  
*C. oliganthus* Nutt. in T. & G. (hairy ceanothus)  
*C. parvifolius* (Wats.) Trel. (littleleaf ceanothus)  
*C. prostratus* Benth. (squaw carpet)  
*C. pumilus* Greene (dwarf ceanothus)  
*C. sanguineus* Pursh. (redstem ceanothus)  
*C. thyrsiflorus* Esch. (blueblossom)  
*C. tomentosus* Parry  
*C. velutinus* Dougl. (snowbrush)  
*C. velutinus* var. *velutinus* Dougl. ex Hook. (snowbrush)  
*C. velutinus* var. *laevigatus* (Hook.) T. & G. (varnishleaf)

### Conifer Species

*Abies amabilis* Dougl. ex Forbes (Pacific silver fir)  
*A. concolor* (Gord. & Glend.) Lindl. ex Hildebr. (white fir)  
*A. grandis* (Dougl. ex D. Don) Lindl. (grand fir)  
*A. magnifica* A. Murr. (California red fir)  
*A. procera* Rehd. (noble fir)  
*Chamaecyparis lawsoniana* (A. Murr.) Parl. (Port-Orford-cedar)  
*Larix laricina* (Du Roi) K. Koch (tamarack)  
*Libocedrus decurrens* Torr. (incense-cedar)  
*Picea sitchensis* (Bong.) Carr. (Sitka spruce)  
*Pinus attenuata* Lemm. (knobcone pine)  
*P. contorta* Dougl. ex Loud. (lodgepole pine)  
*P. coulteri* D. Don (Coulter pine)  
*P. jeffreyi* Grev. & Balf. (Jeffrey pine)  
*P. lambertiana* Dougl. (sugar pine)  
*P. ponderosa* Dougl. ex Laws. (ponderosa pine)  
*P. radiata* D. Don (Monterey pine)  
*P. sabiniana* Dougl. (Digger pine)  
*P. taeda* L. (loblolly pine)  
*Pseudotsuga menziesii* (Mirb.) Franco (Douglas-fir)



*Sequoia sempervirens* (D. Don) Endl. (coast redwood)  
*Sequoiadendron giganteum* (Lindl.) Buchholz (giant sequoia)  
*Thuja plicata* Donn ex D. Don (western redcedar)  
*Tsuga heterophylla* (Raf.) Sarg. (western hemlock)

## Other Species

Trees and shrubs:

*Alnus* Mill. (alder)  
*Arctostaphylos patula* Greene (greenleaf manzanita)  
*Castanopsis sempervirens* (Kell.) Dudl. (bush chinkapin)  
*Holodiscus* Maxim. (ocean-spray)  
*Lithocarpus densiflorus* (Hook. & Arn.) Rehd. (tanoak)  
*Prosopis glandulosa* Torr. var *torreyana* (L. Benson) M.C. Johnst (mesquite)  
*Prunus* L. (cherry, plum)  
*Quercus* L. (oak)  
*Quercus vaccinifolia* Kellogg (huckleberry oak)  
*Quercus kelloggii* Newb. (California black oak)

Mycorrhizal and symbiotic fungi:

*Armellaria mellea* Vahl. ex Fr. (*Armellaria* root disease)  
*Cenococcum geophilum* Fr. (*Cenococcum*)  
*Eutypa armeniacae* Hansf. & Carter. (no common name)  
*Frankia* spp. (*Frankia*)  
*Laccaria laccata* (Scop. ex Fr.) Berk. & Br. (*Laccaria*)  
*Rhizobium japonicum*

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**Conard, Susan G.; Jaramillo, Annabelle E.; Cromack, Kermit, Jr.; Rose, Sharon,** comps. The role of the genus *Ceanothus* in western forest ecosystems. Gen. Tech. Rep. PNW-182. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 72 p.

This report was developed from discussions on the role of *Ceanothus* in western forests that took place at a workshop held November 22-24, 1982, at Oregon State University, Corvallis, Oregon. The workshop provided a forum for discussing research relevant to *Ceanothus* management. Major topics were autecology and synecology; interactions between *Ceanothus* species and the soil system; the physiological ecology of *Ceanothus* and associated conifers; and the effects of *Ceanothus* on forest productivity and growth. The workshop was attended by scientists and land managers from government agencies, universities, and forest industry. This report summarizes available information concerning the biology and ecology of *Ceanothus* species in western forest ecosystems; describes and critiques methods, results, and conclusions of past research; discusses current investigations; identifies research needs; and includes an extensive bibliography and a listing of workshop participants involved or interested in *Ceanothus* research and management.

Keywords: *Ceanothus*, competition (plant), ecology (plant), autecology (plant), synecology (plant).

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# Ecology, Pathology, and Management of Port-Orford-Cedar (*Chamaecyparis lawsoniana*)

Donald B. Zobel, Lewis F. Roth, and Glenn M. Hawk



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## Abstract

**Zobel, Donald B.; Roth, Lewis F.; Hawk, Glenn M.** Ecology, pathology, and management of Port-Orford-cedar (*Chamaecyparis lawsoniana*). Gen. Tech. Rep. PNW-184. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985**. 161 p.

Information about the biology, diseases, and management of Port-Orford-cedar was collected from the literature, from unpublished research data of the authors and the USDA Forest Service, conversations with personnel involved in all facets of Port-Orford-cedar management, and visits to stands throughout the range of the species. Information is summarized and presented regarding species characteristics, distribution, environment, vegetation, autecology, usage, past management, and the biology and effects of the most important pathogen. Recommendations for managing the species in the presence of this pathogen, *Phytophthora lateralis*, were developed. Presence of this introduced pathogen will complicate the management of Port-Orford-cedar and somewhat reduce the area where it can be grown, but production of future crops of cedar should be possible given careful, consistent application of the guidelines presented.

**Keywords:** Autecology, silvical characteristics, silviculture, root rot, ornamental trees, Port-Orford-cedar.

## Summary

Port-Orford-cedar grows naturally in a limited area in coastal northern California and southern Oregon. Distribution is spotty and limited to those sites with the most consistent summer moisture. It grows on sites with a wide variety of soil types (often poor), with a wide range of temperatures, and with many other tree species.

Port-Orford-cedar grows, and can dominate some stands, in all vegetation zones within its range from the coastal Sitka spruce-western hemlock forests to high-elevation true fir forests and open pine-dominated forests on ultramafic soils in the interior. Cedar usually grows with several other conifers. It is most dominant on wet, cool sites on ultramafic soils, but reaches its largest size and commercial value on productive soils along the coast near the northern end of its range. Except on the most mesic, productive soils and some ultramafic areas, understory vegetation is shrubby and dense.

Port-Orford-cedar grows naturally where soil water is abundant throughout the summer. This limits the cedar to certain microsites, topographic positions, or soil types where water is abundant and, sometimes, competition is reduced; its topographic distribution is less limited in climates with higher summer humidity. It can also grow on hot sites with dry air and apparently can control summer water loss at low humidities. The cedar can grow on wetter sites than most associated conifers, but nonstagnant water may be required.

There is no simple explanation for the northern boundary of the range. Cedar appears to be more sensitive to water availability than are the common conifers in the region, but less sensitive to soil nutrient status or temperature.

Dramatic variability in tree form and growth rate occurs among individuals within the species, leading to over 200 cultivated varieties. Some regional variability in growth rate occurs within the species; the variability has not been described well, but seems likely to be of importance in choice of provenance in reforestation. Cultivars also vary in resistance to cold, mineral nutrition, and ability to root, but apparently not in resistance to root rot. Crossing with other *Chamaecyparis* species produces seeds that germinate poorly or seedlings without chlorophyll.

Cuttings of Port-Orford-cedar can be rooted easily, but most natural reproduction is sexual. Reproductive organs are initiated in spring and develop through the summer. Pollination occurs the following spring, and seeds mature by the October after pollination. Both sexes are borne on the same branches. First reproduction occurs at 5-9 years, but with the correct combination of gibberellins and photoperiod, plants only a few months old may be induced to produce viable seed. High seed production can occur in both old and young trees on both poor and excellent sites.

Seed crops seldom fail completely, and good crops occur at 4- to 5-year intervals; crops do not show the regional synchronization that some conifers do. Seed production averages 829 000/ha or 40 000/m<sup>2</sup> of cedar basal area. Seeds are small (2 mg each), but have a short dispersal distance. Most are shed by midwinter, but some seeds fall throughout the year. Germination percent is poor to moderate, but seed can be stored (frozen and sealed) for several years. Stratification is usually not required. Natural germination in the forest appears to be late--in early June. Seedling establishment is increased by soil disturbance and is usually adequate in clearcuttings close (50 to 80 m) to a seed source. Seedlings are easy to grow; a variety of ages of seedlings have been planted successfully, and cold storage of seedlings is possible.

Natural seedlings are small and grow slowly in shade. Growth after the sapling stage is less than for Douglas-fir, except on ultramafic substrates. Most conifers associated with Port-Orford-cedar in its native range are taller than the cedar when they are grown together in European plantations. Tree size varies twofold among natural forest communities. Large, old-growth trees average from about 30 to over 60 m tall and 43 to 86 cm in diameter. Trees 1 m in diameter are usually over 300 years old.

Port-Orford-cedar branches elongate more slowly and for a longer period during each growing season than do those of Pinaceae with which it grows.

Root systems may intermingle and graft freely but tend to be shallow. Roots are mostly of small diameter. Port-Orford-cedar forms vesicular-arbuscular mycorrhizae with several common, wide-ranging fungi.

The nutrient concentrations in Port-Orford-cedar tissue are variable, but the species is generally lower in nitrogen (N), phosphorous (P), and potassium (K) than are associated conifers. In contrast, cedar has higher concentrations of calcium (Ca) and sometimes magnesium (Mg), and a higher Ca:Mg ratio. Growth in culture on four soil types is highly correlated with foliar concentrations of K, and effects of N and P are important. Iron deficiency affects some cultivars.

Litter and soil under Port-Orford-cedar plantations are less acidic than those under associated Pinaceae. Development of amorphous humus is much less obvious than under Pinaceae.

Throughout its range, Port-Orford-cedar is shade tolerant and reproduces in old-growth stands, and it can act as both a pioneer and a climax species in the same stand. It reproduces in the shade more effectively than associated conifers do, except for western hemlock and sometimes white fir. Dense, young stands and some microsites in well-developed old growth are, however, too dark for its survival. The species usually establishes well, sometimes aggressively, in clearcuttings and other disturbed areas when seed is available. Its presence in mixed stands is thought to have little effect on productivity of more dominant species.

The extent of frost damage varies considerably as compared to associated conifers. Winter damage to Port-Orford-cedar usually results from desiccation rather than from low temperature alone. Port-Orford-cedar appears not to be especially susceptible to damage by wind or snow and can grow with moderate air pollution. Large trees have thick bark and survive fire. Many old-growth stands have burned repeatedly, and large fire scars are common. Small trees do not appear to have particularly great fire tolerance. Cedar rapidly reinvades burns and fire-killed snags may remain merchantable for special uses for decades.

Port-Orford-cedar has few biotic enemies that cause widespread serious damage, although effects of browsing are variable. The exception is a root rot caused by *Phytophthora lateralis* that has spread throughout much of the cedar's range since 1952. Stands have been eliminated from some habitats, and the commercial status of the species is threatened throughout its range.

The root rot attacks only Port-Orford-cedar, and it kills trees of all sizes in all environments where the species is exposed to it. The root rot spread from an unknown source into ornamental plantings outside the native range, from there throughout the northern part of the commercial range, and now has reached all but the more remote areas of the range of the cedar. There is no known genetic resistance or established chemical control. The root rot moves in water via aquatic spores; as spores in mud transported by people, machinery, or animals; or by growing through root grafts between adjacent trees. Dry conditions reduce the danger of spread by spores but do not kill the fungus or its resting spores. The few data available indicate that soil at an infected site will contain infectious spores for 3 years after the last host tree has died.

Wood from Port-Orford-cedar has been used for many purposes, but its use has been limited by its supply, first to the Pacific Coast; then to certain specialty products; and, since the 1950's, to the export market, particularly Japan. High prices have been paid for it almost throughout its history. Production peaked in the 1920's and has generally declined since, although prices have continued to rise. Harvest has been accelerated by the effects of root rot and presently exceeds growth.



Heartwood of Port-Orford-cedar is relatively strong and light, very resistant to decay, and easy to machine; it can fill a large variety of uses. Wood produced by second growth is as suitable for structural use as is old growth. In contrast, wood grown in Great Britain is less desirable, relative to other species, than that from the United States. Since the 1960's, the high price for old-growth timber has depended more on the aesthetic value of wood exported to Japan than on the intrinsic physical or chemical properties of the wood. Oil in Port-Orford-cedar wood is toxic to termites and other decay organisms, and may also cause discomfort in workers continually exposed to it.

Mean annual volume increments of 60-year-old stands in Oregon are about 14 to 17 m<sup>3</sup>/ha. Stands in Great Britain are grown more densely than other conifers, and mean annual increment peaks at age 55-70, 5-15 years later than for Douglas-fir. Some stands of old growth have yielded over 1400 m<sup>3</sup>/ha; some small areas still bear 280 m<sup>3</sup>/ha. Large areas average much less--40 to 150 m<sup>3</sup>/ha over several hundred hectares.

Although management in the presence of the root rot is difficult, we believe that future rotations can be produced, and that management of cedar can be beneficial for economic as well as for aesthetic and biological reasons. Management requires long-term commitment by the landowner, however, and must emphasize allowing cedars to escape the disease. Spread of inoculum must be limited and can be accomplished by keeping equipment clean, working in dry weather, and eliminating pockets of infection. Cedar must be limited to specific locations that are unlikely to become infected. Limiting access, locating roads, and conducting all management activities so that spores do not reach stands are important.

Not much planting of Port-Orford-cedar has been done, but the little that has, has been successful. Precommercial thinning may unintentionally eliminate cedar as a crop tree if done by size alone. Some control of cedar density and tree location can both preserve cedar in the stand and reduce the chance of tree-to-tree spread of root rot.

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Port-Orford-cedar (*Chamaecyparis lawsoniana* [A. Murr.] Parl.) is a valuable forest tree within its limited geographic range. Its value has increased faster than that of the major lumber species in both the domestic and foreign markets (Ruderman 1979) and reached a stumpage price in one sale of \$5,440 per thousand board feet (USDA, Forest Service 1979). Demand for its wood, almost all of which is exported to Japan, continues to be high and has not been closely synchronized with fluctuations in the domestic market. Significant problems beset the continued production of the species, however. Slow growth (relative to Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]) and losses to frost and animals in plantations outside its natural range diminished silvicultural interest in Port-Orford-cedar (Hunt and Dimock 1957, James 1958). During a period of low demand, and following the introduction of a devastating root rot, interest essentially disappeared. The root rot continues to spread, and no usable natural resistance has been found. The dilemma of managing a valuable but slow-growing, less common conifer in mixed stands, in an age of high interest rates and shortened rotation periods (as Minore [1983] discussed for western redcedar), is exaggerated for Port-Orford-cedar. Even so, as the price of Port-Orford-cedar has risen, interest in managing the species has increased and foresters are reassessing the possibility of sustainable production in spite of root rot.

Although the biology of the fungus, *Phytophthora lateralis*, that causes the fatal root rot of Port-Orford-cedar is incompletely known, useful information has accumulated. Once a tree is attacked there is no known cure, but the fungus seems to disappear rapidly from the soil once the cedar dies. The major natural agent that disperses the fungus is running water. Mud moved by machinery from an infected to an uninfected stand provides the principal effective inoculum. The movement of the pathogen can be predicted and, to a lesser degree, controlled. Management without both resistance of the tree to infection and an effective control method may be possible, given sufficient collaboration among pathologists and forest managers.

Port-Orford-cedar became commercially important as an ornamental in Europe soon after its discovery by horticulturists in 1854. Over 200 cultivars have been produced that vary in size, form, color, and foliar patterns; some have been used for over a century. The cultivars are most popular in Europe, but are used in many temperate areas. The cedar root rot, originally described from an ornamental nursery in Washington, destroyed a thriving nursery industry in the Pacific Northwest that had been based on cedar.

Port-Orford-cedar presents some problems of considerable interest to ecologists: What attributes allow it to grow on many ecologically different sites, but at the same time severely limit its geographic distribution? Why is growth of Port-Orford-cedar less affected on sites and at ages that drastically curtail growth of the regionally dominant conifers? Port-Orford-cedar possesses the unusual combination of tolerance to shade, and, by midlife, to fire. A member of the family Cupressaceae, its ecology may differ significantly from the conifers of the Pinaceae, which are the most often studied.

## Chapter 2: Geographic and Habitat Distribution

Our purposes are to review the biology of Port-Orford-cedar and its most important pathogen, to review the history of its management, and to propose guidelines for its future management in the presence of the root rot. Information from past and current unpublished research and management practice is used, as well as the rather limited literature on the species. Much of the literature, unfortunately, is based on work outside the native range.

Port-Orford-cedar is native only to southwestern Oregon and northwestern California (Little 1971) in the Klamath Mountains, the southern end of the Coast Range in Oregon, and the northern end of the Coast Ranges in California, and on coastal and alluvial terraces and coastal dunes. Its distribution is highly localized within most of its range (figs. 1 and 2), and the extent of stands is hard to estimate accurately.

The USDA Forest Service range map (Little 1971) incorrectly shows that the cedar is present on the immediate coast of southern Oregon, although its absence is clearly indicated on an earlier map (Port Orford Cedar Products Company 1929). The northern disjunct location in Lane County, OR (shown by Little 1971), has been difficult to relocate, except for planted trees. A forest survey plot indicating Port-Orford-cedar in Lane County, OR, appears to contain western redcedar (*Thuja plicata* Donn ex D. Don) instead.

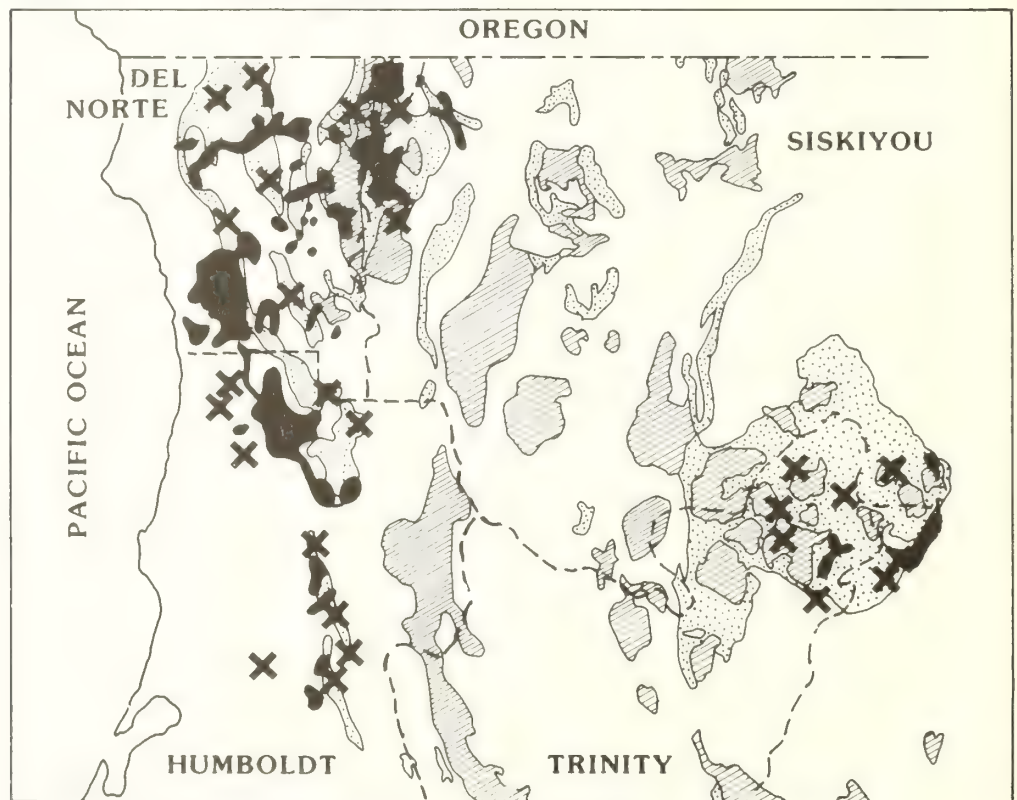


Figure 1.—Distribution of Port-Orford-cedar in California in relation to geology. Redrawn from Griffin and Critchfield (1972) and Page (1966). Black areas and X's are locations of cedar; stippling indicates ultramafic rocks; hatching indicates granitic rocks; dashed lines are county boundaries.

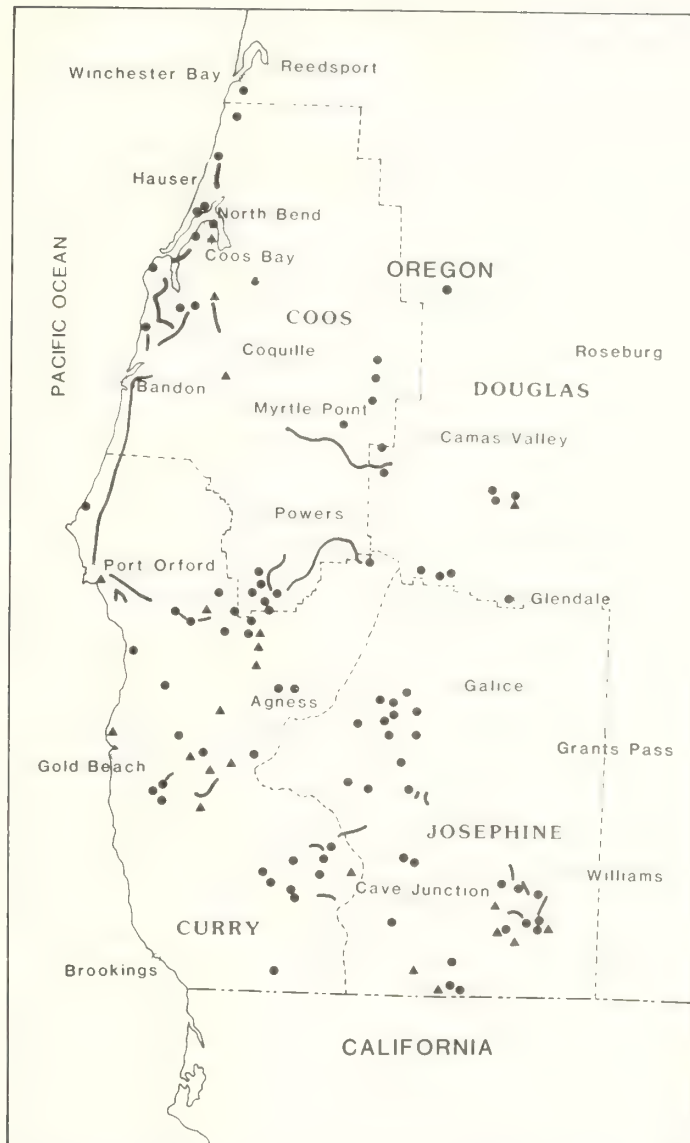


Figure 2.—Distribution of Port-Orford-cedar in Oregon. Locations indicated by (▲) are those of herbarium specimens; those indicated by (●) are observations by recent observers looking specifically for the species or are from a 1925 USDA Forest Service map. Dark lines are roads along which the species has been observed at least once every mile. Cities are shown as (o).



The greatest concentration of Port-Orford-cedar is in Oregon in the northern third of its range, on the coastal hills and terraces from Coos Bay to Port Orford and in the adjacent southern edge of the Coast Range in Oregon, including the drainages of the middle and south forks of the Coquille River. Secondary concentrations occur inland at moderate to high elevations near the Oregon-California border, and in the watersheds of Grayback Creek and Deer Creek in southeastern Josephine County, OR (Atzet 1979, Hawk 1977), and of upper Clear Creek in northwestern Siskiyou County, CA (Siemens 1972). Throughout most of its range, however, Port-Orford-cedar grows in small, disjunct stands. A group of stands widely separated from the bulk of the range occurs inland in California along the upper reaches of the Trinity and Sacramento River systems near the juncture of Siskiyou, Shasta, and Trinity Counties. Early sources (Port Orford Cedar Products Company 1929, Sudworth 1908) indicate its presence farther south than is shown on recent range maps.

Port-Orford-cedar grows from sea level (Hawk 1977) to subalpine forests (Siemens 1972). It reaches 1950 m in the upper Sacramento River drainage.<sup>1</sup> Cedar occupies dune sand; organic bog soils; soils developed on diorite, gabbro, serpentine, peridotite, several other rock types, and river alluvium; the Blacklock soil series on coastal terraces (which supports only pigmy conifers in Mendocino County, CA) (Jenny and others 1969, Westman 1975); and in the area of its greatest commercial value, soils developed on sedimentary rocks. Climate varies; the cedar's range includes the coastal fog belt, relatively dry interior valleys, and extends into the subalpine. Port-Orford-cedar occurs in all four vegetation zones recognized in southwestern Oregon (Franklin and Dyrness 1973) and in the montane, subalpine, mixed evergreen, and north coastal forest regions of northwestern California (Barbour and Major 1977). The tree also occurs in local azonal vegetation types on coastal dunes, inland river terraces, and bogs on ultramafic outcrops (Hawk 1977). Port-Orford-cedar grows on a variety of land forms.

The diversity of habitat implied by the preceding description does not occur on a local basis, however. Within a given locality, the tree is often restricted to a single edaphic situation; that is, to sites with year-round seepage throughout much of its range, and in addition, inland at low elevations south of Coos County, OR, to soils from ultramafic parent materials (peridotite, serpentinite). At its northern limit, it grows on Recent and Pleistocene coastal sand dunes. Where it is most prevalent, Port-Orford-cedar occupies a wider variety of land forms and substrates. The general relationships of elevation, parent material, geographic location, and forest type where Port-Orford-cedar is usually found are shown in figure 3.

### Chapter 3: Environment Climate

The climate where Port-Orford-cedar grows has warm, dry summers and cool, wet winters, but varies considerably with proximity to the ocean and with elevation (fig. 4, table 1). Long-term climatic data are available for a few coastal and valley-bottom weather stations (table 2). There is a 10 percent chance of frost (0 °C) during 165 days per year at North Bend (on the coast), 243 days at Powers (in the Oregon Coast Range), and 307 days in Josephine County (in the Klamath Mountains) (Eichorn and others 1961, Sternes 1968). The climate is described by Atzet (1979), Buzzard and Bowlsby (1970), Cooper (1958), Hawk (1977), Major (1977), Meyer and Amaranthus (1979), Sternes (1968), and Whittaker (1960).

<sup>1</sup>Personal communication, 1980, R. Kelly, Berkeley, California.

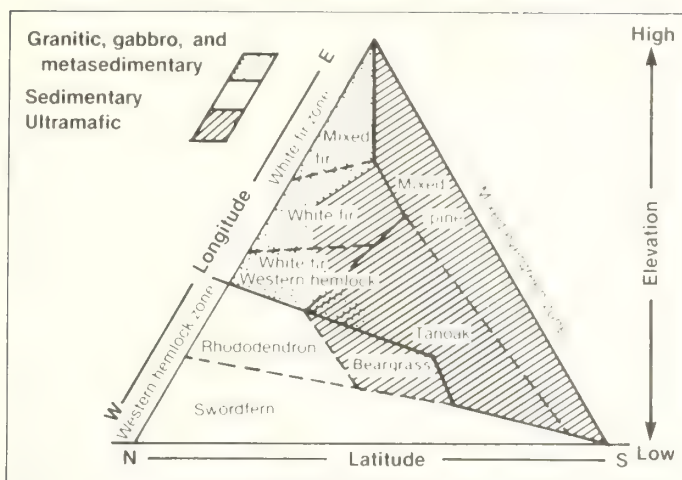


Figure 3.—Distribution of vegetation zones and eight major forest communities of old-growth Port-Orford-cedar in relation to soil parent material, elevation, and geographic location. Zones (described in Chapter 4) are separated by heavy solid lines and communities by dashed lines (modified from Hawk 1977).

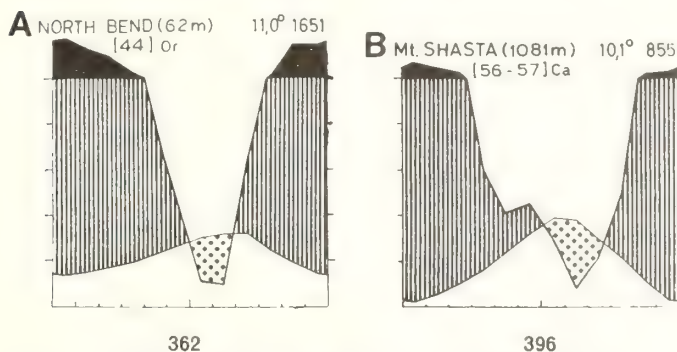


Figure 4.—Climate diagrams (Walter and others 1975, used courtesy of Springer-Verlag New York, Inc.) representing (A) the northern coastal range and (B) the area just outside the interior southern parts of the range of Port-Orford-cedar. The x-axis represents months of the year. The lower curve on the graph represents temperature, the upper curve precipitation. The stippled portion represents the relative period of drought. Figures in the top line are elevation, mean annual temperature ( $^{\circ}\text{C}$ ), mean annual precipitation (millimeters), and (years of record).

**Table 1—July and January mean temperature data for the range of Port-Orford-cedar in Oregon and California**

(In degrees Celsius)

Item	Oregon	California
July:		
Mean minimum	7 to 12	8 to 12
Mean maximum	20 to 32	18 to 33
January:		
Mean minimum	-2 to 5	-3 to 5
Mean maximum	6 to 12	6 to 12

Source: Hawk 1977.

**Table 2—Climatic variation within the range of *Chamaecyparis lawsoniana*, 1951-60**

Region and station	Latitude (N)	Distance inland	Elevation	Precipitation			Mean temperatures		
				Annual	Jun-Aug	Snow	Annual	Coldest month minimum	Warmest month maximum
		km	m	- - - - - mm - - - - -			- - - - - °C - - - - -		
Coast:									
North Bend FAA-AP	43°25'	5	3	1579	64	3	11.2	4.2	19.0
Klamath	41°31'	3	8	2185	62	ND	11.6	4.1	19.8
Coast Ranges and Siskiyou:									
Sitkum 2 SW	43°08'	43	173	2159	73	201	11.6	1.7	25.5
Powers	42°53'	34	92	1655	56	ND	11.9	2.5	24.3
Illahe	42°39'	28	113	2253	48	363	13.1	2.3	31.4
Oregon Caves									
National Monument 1/	42°06'	68	1220	1753	64	4445	7.8	-2.3	25.9
Elk Valley	42°00'	41	357	2187	44	ND	10.4	- .3	30.1
Interior California:									
Mount Shasta WB									
City 2/	41°19'	149	1081	1019	37	3550	9.8	-3.3	29.7
Dunsmuir	41°13'	152	738	1590	52	ND	ND	ND	ND

ND = no data given.

1/ Data for 7 years from Atzet (1979).

2/ Station outside, but within 5 km, of range of *C. lawsoniana*.

Source: U.S. Weather Bureau unless otherwise noted.



**Table 3—Snow depths at snow survey sites in the range of Port-Orford-cedar**

Location	Elevation	Measurement date	Years of data	Mean depth	Range of depth
	<u>Meters</u>			<u>- Centimeters -</u>	
Page Mountain, Josephine Co., OR	1235	Jan-Apr 1/	18	53	3-183
Mumbo Basin, Trinity Co., CA	1739	April	13	161	64-274
Gray Rock Lakes, Siskiyou Co., CA	1891	April	17	264	165-526

1/ The data used are, for each year, the maximum of 3 measurements, 1 each taken in late January, late February, and late March to early April.

Source: George and Haglund 1973, Hannaford 1959.

Total precipitation is moderately high. The eastern boundary of the range in southern Oregon coincides approximately with the 1000-mm limit (USDA Soil Conservation Service 1964). In California, most stands receive at least 1500 mm (Rantz 1968), and inland disjunct populations receive at least 1250 mm precipitation. South and east of its range, in general, rainfall decreases and evaporative stress increases (Johnsgard 1963, Thornthwaite Associates 1964, Walter and others 1975). Along the coast south of the range, however, are areas with the same precipitation and evaporation as within the range of Port-Orford-cedar so, unlike the drying along the eastern boundary, there appear to be no abrupt climatic changes across either the southern or the northern ends of the range.

A major climatic break within the range exists between the Coquille River drainage, with its extensive commercial stands of Port-Orford-cedar, and the adjacent Rogue River Valley to the south. The Coquille valleys, open to the northwest, often have low clouds borne on strong northwest winds in the summer; the clouds often dissipate as they cross into the Rogue River Valley, which is open to the dry interior valleys to the east. Fog along the lower Rogue River is common but usually restricted to the valley bottom. Temperature differences between Powers and Illahe demonstrate the more maritime climate in the Coquille drainage at Powers (table 2).

Snowfall varies from rare along the coast to an accumulated snow pack of 1 m or more at high elevations (tables 2 and 3) (Sternes 1968).

Relative humidity along the coast in Oregon is high, with a monthly average at 4:00 p.m. of 71 to 74 percent during the growing season and 82 percent in January. The average monthly reading for 4:00 a.m. is never below 89 percent. Two-thirds of the days (ranging from 30 percent of days in July to 80 percent of days in January) are cloudy in this area (Buzzard and Bowsby 1970). The daily minimum humidity at Oregon Caves National Monument at 1200 m elevation in southeastern Josephine County, OR, averages 39 percent and the maximum is

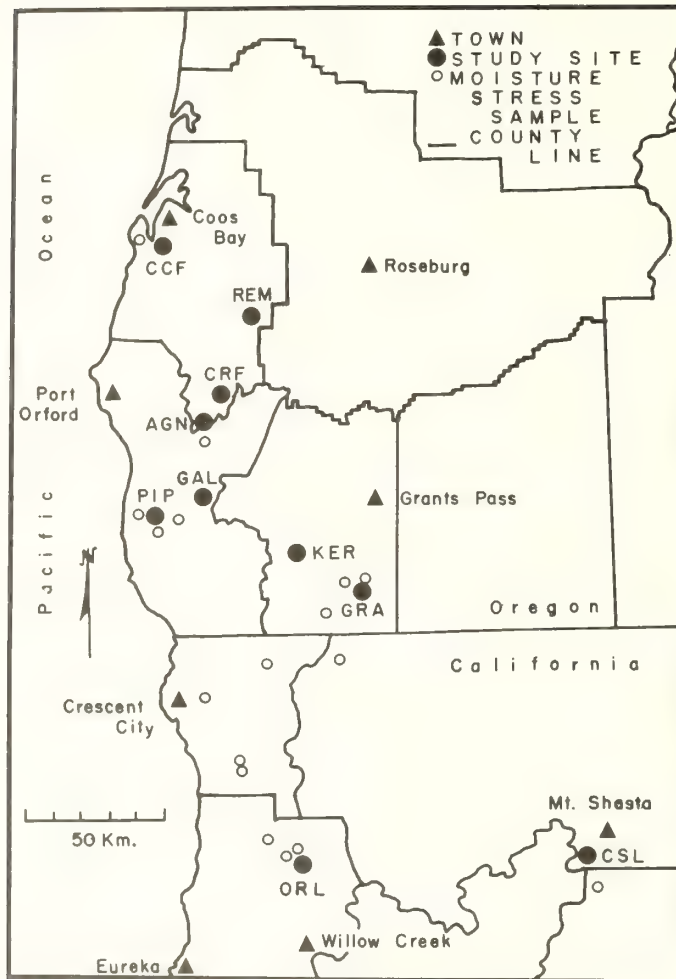


Figure 5.—Ten primary study sites where temperature, foliar nutrient content, understory light intensity, water potential, and seed production were sampled, and of secondary sites used for sampling water potential. Sites, north to south, are: CCF, Coos County Forest; REM, Remote; CRF, Coquille River Falls; AGN, Agness Pass; GAL, Game Lake; PIP, Pine Point; KER, Kerby; GRA, Grayback; ORL, Orleans; CSL, Castle Lake (from Zobel and Hawk 1980 used courtesy of *American Midland Naturalist*).

84 percent during the driest month (Atzet 1979). In contrast, humidity in open, low-elevation stands can be very low. Vapor pressure deficit reached 47.5 millibars at Kerby (fig. 5) and averaged 23.5 millibars for the driest day in the one summer measured; the maximum reached at Coos County Forest on the coast that summer was 10 millibars (Zobel and Hawk 1980). Fog is common along the coastline and morning fog also occurs along the lower part of major drainages in the Oregon Caves area (Atzet 1979).

Average wind speed at Coos Bay is lowest in autumn and highest in July (Buzzard and Bowlsby 1970). Summer winds (May to September) are almost all from north to northwest. From November to March, winds from the south to southwest are

Table 4—Temperatures in the air, 1 m above the soil, and in the soil, 20 cm below the forest floor, under stands of Port-Orford-cedar, September 1974 to September 1976

Vegetation type and community	Site	Air temperature			Frostless season in 1975	Soil temperature		
		Mean annual	Minimum in coldest month 1/	Maximum in warmest month 1/		Annual	Coldest month	Warmest month
		- - - - - °C - - - - -				- - - - - °C - - - - -		
				days				
<u>Vegetation heterophylla:</u>								
Sandstone	Coos County Forest	8.9	+2.2	17.7	225	9.8	6.8	13.2
Swordfern	Remote	8.2	+ .8	19.0	197	8.3	4.1	13.2
	Coquille River Falls	8.4	+ .8	22.7	185	7.9	4.0	12.2
<u>Mixed evergreen:</u>								
Tanoak	Agness	6.9	-2.1	25.2	155	7.6	3.6	13.5
	Pine Point	8.8	- .3	23.5	124	9.2	5.4	13.7
	Orleans	7.5	-1.0	22.2	NA	6.9	5.1	9.1
Mixed pine	Kerby	10.9	- .4	34.9	233	11.3	8.3	15.0
<u>Vegetation concolor:</u>								
White fir	Game Lake	NA	-1.6	20.1	NA	NA	NA	12.3
	Castle Lake	4.4	-6.7	23.6	52	3.9	.4	9.0
Mixed fir	Grayback	5.7	-2.7	18.4	NA	4.8	1.4	9.3

1/ = insufficient data available.

2/ "Warmest month" and "coldest month" data are means of the mean maxima and minima of air, and the mean monthly temperature of soil for the appropriate months in both years of the study.

Source: Zobel and Hawk 1980.

strongest and most common.<sup>2</sup> Storm winds can be severe. On November 13, 1981, for example, wind speed reached 198 km per hour at 61 m elevation at a typical site in coastal Coos County, and remained above 80 km per hour for 7 hours (see footnote 2).

Table 4 and figure 6 summarize means of temperatures for 2 years as measured 1 m above the forest floor in 10 natural cedar forests throughout the range (Zobel and Hawk 1980). The extreme low air temperature recorded within the range was -15 °C (compared with a low of -19 °C for the Mount Shasta U.S. Weather Bureau station). Temperature fluctuations within the range appear to be synchronized by the movement of air masses inland from over the ocean. Areas near the coast show the most variation from the general pattern as summer fog usually coincides with hot weather inland. In the region where Port-Orford-cedar grows, summer temperatures remain higher later in the year than they do in surrounding areas. This pattern, which results in warmer September averages, is obvious in the northern part of the range and even more so for temperatures in stands than for those at the nearest weather stations (Zobel and Hawk 1980).

<sup>2</sup>Personal communication, 1984, J. Wade, Oregon State University, Corvallis.



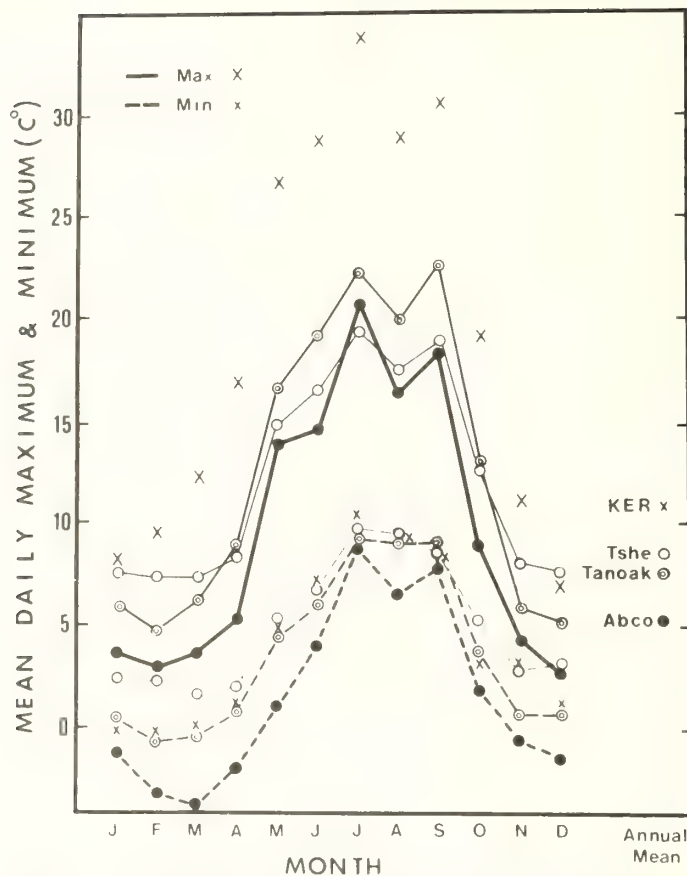


Figure 6.—Mean daily maximum and minimum temperature in the forest understory, and annual mean temperature by zone. Mixed Evergreen zone data are presented separately for the tanoak community and for the mixed pine community at Kerby (X). "Abco" represents the *Abies concolor* zone; "Tshe" is the *Tsuga heterophylla* zone. Sites sampled are listed in table 4 and their locations are shown in figure 5 (from Zobel and Hawk 1980, used courtesy of American Midland Naturalist).

Port-Ordord-cedar stands are generally cold and temperature varies relatively little during the year (fig. 7, table 5), especially on sites with active year-round seepage. Soils do not appear to freeze often, even at high-elevation sites. Port-Ordord-cedar grows on many of the available substrates (table 6) and landforms (table 7).

Some definite relationships occur among substrate, topography, and other environmental factors in the habitat of Port-Ordord-cedar (see fig. 3) (Hawk 1977, Whittaker 1960, Zinke 1977).

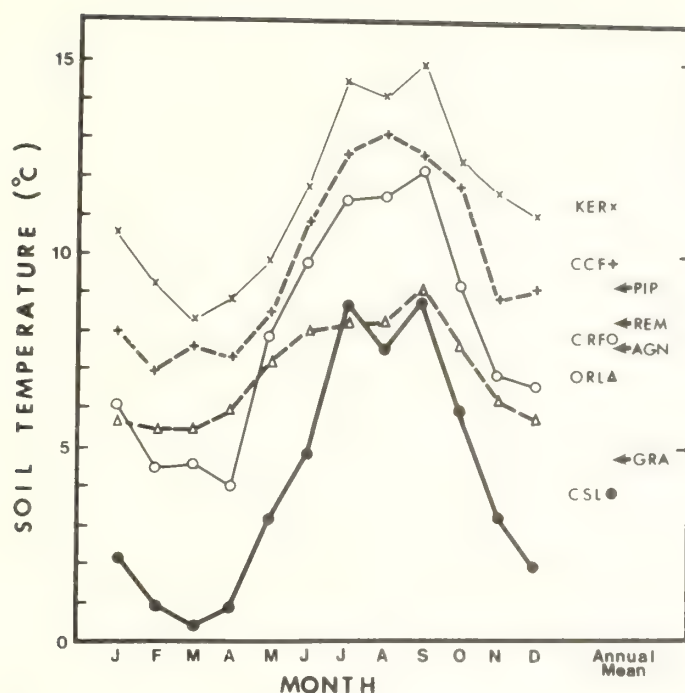


Figure 7.—Mean monthly soil temperature (20 cm deep) for five sites, with mean annual soil temperature for nine sites. See table 4 and figure 5 for site characteristics and locations (from Zobel and Hawk 1980, used courtesy of *American Midland Naturalist*).

**Table 5—Mean maximum and minimum temperatures of litter and soil at four sites, valley of the South Fork Coquille River<sup>1/</sup>**

(In degrees Celsius)

Period	Litter		-10 cm soil	
	Minimum	Maximum	Minimum	Maximum
16 Jun-15 Jul	8.9	12.2	9.7	10.3
16 Jul-15 Aug	11.2	15.5	12.3	13.0
4 Sep-26 Sep	11.4	14.7	12.1	12.7
3 Jan-5 Jan	6.1	6.9	5.9	6.1
Extreme values	- .2	16.9	2.2	14.5

<sup>1/</sup> Data are means for the period indicated in the understory in four forests for 1979 to 1980, except "extreme values," which are the highest or lowest recorded at any site during the entire period.

Source: Imper 1981.

**Table 6—Predominant rock types that underlie 105 stands throughout the range of Port-Orford-cedar**

Rock type	Number of stands
Ultramafic (peridotite, serpentinite)	51
Diorite, gabbro, other intrusive	22
Sedimentary	21
Recent alluvium	4
Schist	3
Metavolcanic	2
Others	2

Source: Hawk 1977.

**Table 7—Landform and position of 98 stands throughout the range of Port-Orford-cedar**

Landform	Position		
	Top slope	Midslope	Bottom slope <u>1/</u>
Ridgetop	--	1	--
Sideslope	7	27	--
Bench	12	20	--
Drainageway	5	25	1

-- = none.

1/ Absence of sampling plots on the bottom slope position reflects in part the almost universal disturbance of Port-Orford-cedar forests in these areas.

Source: Hawk 1977.



Port-Orford-cedar grows in a region that has extremely complex geological patterns (Baldwin 1974; Baldwin and others 1973; Beaulieu and Hughes 1975; Davis 1966; Dott 1971; Harper 1983; Hotz 1971; Irwin 1981; Page 1966; Ramp 1975; Ramp and Peterson 1979; Ramp and others 1977; Robertson 1982; Strand 1969, 1973; and Whittaker 1960). The major commercial forests and the northern extremity of the range in Coos County are underlain primarily by Eocene sedimentary rocks. A primary source area for these sediments was the complex, older Klamath Mountains province to the south, which includes most of the range of Port-Orford-cedar. North, beyond the range of the cedar, the source and physical nature of the sediments changes, but no significant differences in the chemical composition of rocks inside and outside the range have been noted (Dott 1966).

Near the northern limit of Port-Orford-cedar in Coos County, the species is most common on Quaternary sediments on marine terraces, sand dunes, deflation plains, and the underlying Eocene Coaledo formation sedimentary rocks within 6-7 km of the ocean. At the apparent northeastern limit in Douglas County (see fig. 2), old trees occur primarily on north-facing cliffs on siltstone of the Eocene Tyee formation, although the cedar has become more widespread following clearcutting. South of Coos Bay, the best-developed, early-exploited forests of Port-Orford-cedar (Sargent 1881) grew on high terraces along the coast and on several Eocene sedimentary formations on slopes below the terraces. Inland, in the higher elevations of the southern Coquille River drainage, the trees grow on Eocene sediments (apparently primarily Lookingglass and Tyee formations) and Quaternary alluvium, as well as on the Jurassic Galice formation and accompanying ultramafics, which comprise the northern end of the Klamath Mountain Rocks.

In the Klamath Mountains, the oldest Paleozoic rocks are in the eastern portion just north of Redding, CA. Four convex bands of successively younger rocks (to Jurassic) occur to the west, extending north to Douglas and southern Coos Counties, OR. These sediments and volcanics have mostly been metamorphosed and are accompanied by large bodies of ultramafic rocks, which lie in arcs along major fault zones separating the bands of differently aged rocks. Most of the ultramafic rock is peridotite; much of it has been converted to serpentinite. Granitic rocks intruded at a later time. The region was subjected to intense faulting and deformation and repeated uplift until the early Eocene.

Some populations of Port-Orford-cedar along the lower Klamath River and its tributaries grow on the Franciscan formation, which lies west of Klamath Mountain rocks at the north end of the California Coast Ranges.

The Klamath Mountains are rugged and deeply dissected; much of the terrain is unstable, especially that underlain by ultramafic rocks and schists. The highest areas of the Klamath Mountains in California were modified by local alpine glaciation, and Port-Orford-cedar occupies moraines near its upper elevational limit in Cedar Basin, in the upper Sacramento River drainage.<sup>3</sup> The topography is lower and more subdued on younger rocks along the coast and in the north, but the mountains are still steep. Along the coastline, especially in the north, flat, wave-cut terraces occur up to 500 m above present sea level.

<sup>3</sup>Personal communication, 1983, J.O. Sawyer, Humboldt State University, Arcata, California.

**Table 8—Rock types that underlie vegetation units with >5 percent cover of Port-Orford-cedar in mountains along the lower Klamath River and west of the lower Trinity River, Humboldt and Del Norte Counties, CA**

Importance	Number of stands	Serpentine	Ultrabasic igneous	Metamorphosed basic igneous	Schistose sedimentary	Sandstone and shale	Soft sedimentary rocks
----- Percent -----							
>5 percent	13/	2	15	13	51	17	2
Important 1/	72	--	14	22	44	17	3

-- = none.

1/ "Important" means the species was the first or second most abundant species.

Source: USDA Forest Service and others 1960-1962.

In the valley of the South Fork Coquille River, Port-Orford-cedar is important on a wider local variety of rock types and topography than anywhere else (Hawk 1977). The best development of the cedar seems to occur in topography created by land slumping, such as at Coquille Falls Research Natural Area. In the Klamath Mountains geologic province in and south of the Rogue River Valley (especially at low elevations), Port-Orford-cedar is limited primarily to benches and drainageways in or below ultramafic rocks (Hawk 1977, Zinke 1977). Major exceptions are in the highlands of southeastern Josephine County, OR, and near the mouth of the Klamath River in California. In southeastern Josephine County, Port-Orford-cedar is common on a large intrusion of diorite (Whittaker 1960), and importance of cedar increases above 800 m. In the upper South Fork Deer Creek drainage, cedar occurs on metavolcanic rocks of the Applegate group. In the coastal mountains along the lower Klamath River and west of the lower Trinity River (areas not sampled by Hawk [1977]), Port-Orford-cedar grows on a variety of rock types with the majority of mapping units located on sedimentary rocks (table 8). West of Orleans, CA, it grows on the Galice formation (Sawyer 1980, Sawyer and others 1977).

Stands from the Coast Range in Oregon and high elevations in the northern Klamath Mountains often occupy top-slope positions and side-slope landforms. In contrast, low-elevation and southern Klamath Mountain forests are most common on benches and in drainageways. Soils in 81 percent of the plots in Hawk's (1977) major communities developed from colluvial materials; 47 percent of the parent materials were entirely colluvial, especially in sedimentary and less basic intrusive rocks. In contrast, only 28 percent included some alluvium and 32 percent were partially from residual parent materials (mostly on ultramafic rocks).

In most areas, a critical factor for the presence of Port-Orford-cedar seems to be a consistent supply of seepage water. Substratum and topography contribute to occurrence of seepage but do not themselves seem to be sufficient for presence of the tree. South of the Coquille River drainage, all stands sampled (fig. 5) had a water table within 70 cm of the surface (Zobel and Hawk 1980). Seepage was often obvious and rapid. On ultramafic substrates, the water table was perched above a dense layer of fine clay.

**Field characteristics.**—Summary descriptions of soil profiles presented here (tables 9 and 10 and in text) for eight major forest communities (see Chapter 4) where Port-Orford-cedar occurs are from Hawk's (1977) vegetation plots located throughout the range.

*Swordfern community.*—Most stands occur on benches of shallow relief, and all occur on sedimentary parent materials.

*Rhododendron community.*—All stands occur on sedimentary parent materials. These soils include coarser fragments, are better drained, are on generally steeper topography, and are on upper slopes or side slopes rather than on benches or terraces, in contrast to the swordfern community.

*Beargrass community.*—Stands all occur on ultramafic parent material (mostly serpentinite, but also some dunite and peridotite). The two major areas are in the contact zone between ultramafic and granitic formations, with some metamorphosed sedimentary rocks also present. Average soil depth to the C horizon is only 47 cm; soils on ultramafic rocks are shallower (35 cm) than those including other parent materials (59 cm). These soils occur typically on side slopes or undulating topography similar to that of the rhododendron community.

*Tanoak community.*—This community occurs on ultramafic substrates similar to those of the beargrass community but where moisture conditions are similar to those of the rhododendron community. It is commonly found on perennial stream drainage benches and on gently rolling topography with common seeps or standing water.

*Mixed pine community.*—All stands in this community occur on either weakly weathered serpentinite or, most commonly, peridotite. This community has been separated by Hawk (1977) and Whittaker (1960) into shrub- and herb-matrix phases, which occupy noticeably different microhabitats. The shrub phase occurs on benches and drainages with slopes averaging about 15 percent; the herb phase occurs on midslopes with an average slope of 34 percent. Depth to the surface of the C horizon averages 32 cm (42 cm in the shrub phase and 19 cm in the herb phase).

*White fir-hemlock community.*—Parent materials include quartz diorite, metavolcanics, mixed gneiss, schists, and gabbro, all of which are complexly intruded with peridotite and serpentinite. A mixture of metavolcanic, metasedimentary, and ultramafic rocks is common within most soils. Soils are comparatively shallow, typically developed on colluvium, or mixed alluvium and colluvium, and contain much coarse material.

*White fir/herb community.*—The predominant parent material is at least partially ultramafic with some volcanic materials at a few locations.

*Mixed fir/herb community.*—Parent materials are variable, with many being dioritic colluvium. Some stands occur on sedimentary or volcanic parent material. Soils are usually moist and well-drained, and contain many coarse fragments. Most are deep and moderately developed. This is the coarsest group of soils in any of the eight major plant communities.



**Table 9—Soil depth, to the top of the C horizon, and soil texture, by horizon, for eight major plant communities of Hawk (1977)**

Community	Depth (A+B horizons)		Texture by horizon 1/		
	Mean	Range	A	B	C
	- - - Centimeters - - -				
Swordfern	67	40-117	gSL	g,coSCL	g,coSCL
Rhododendron	73	40-100	SL	g-coSL	g,coSCL
Beargrass	47	15-95	gSL	g,coSCL	g,co,stCL
Tanoak	69	28-105	g,coSL	g,coSL-SCL	g,co,stSCL
Mixed pine	32	5-50	g,stL-C	g,co,stSCL	g,co,stSC-C
White fir-hemlock	43	23-70	g,coSL	g,co,stSCL	vg,co,stSa-
White fir	41	21-65	g,coSL	g,coSL-CL	vg,coSL-CL
Mixed fir	65	30-105	g,coSL-SaL	vg,coSaL	vg,coSaL-L

1/ S = silt or silty; Sa = sand or sandy; C = clay; L = loam; g = gravelly; co = cobbly; st = stony; v = very; - = to.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

**Table 10—Structure, dry consistency, and wet consistency of surface soils and subsoils for eight major plant communities of Hawk (1977)**

Community	Surface soils			Subsoils		
	Consistency			Consistency		
	Structure 1/	Dry 2/	Wet 3/	Structure 1/	Dry 2/	Wet 3/
Swordfern	SM-CG,Cr	Fr	sStP-nSnP	S,MSB or MX	F	StP
Rhododendron	WF-MCr, G	L-F	nSt,nP	MCG-SB or MX	Fr-H	sStP-StP
Beargrass	S-M,F-C,G	Fr	nStP-s StP	SG-SB or MX	F	sSt,np-StP
Tanoak	S,F-MG	Fr	sStP	S-M,F-CSB or MX	Fr-F	StP
Mixed pine	MF-MeGr	L-H	sStP	W-M,vF-CGr or SB	L-H	StP
White fir-hemlock	W-M,FCr-MeSB	Fr	vsSt,nP	SF-C,SB-MX	Fr-F	sStP
White fir	WvFCr	L-F	sSt,s-nP	WvF-CGr-SB or MX or LSG	Fr-F	sStP
Mixed fir	WF-CG,Cr	L-F	nStP-sStP	W-S,vF-CG-MeSB or MX	Fr-F	StP

1/ S = strong; M = moderate; W = weak; C = coarse; Me = medium; F = fine; LSG = loose single grain; G = granular; Cr = crumb; SB = subangular blocky; AB = angular blocky; MX = massive.

2/ L = loose; Fr = friable; F = firm; H = hard.

3/ St = sticky; P = plastic; nSt = nonsticky; nP = nonplastic; StP = sticky and plastic; s = slightly; v = very.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

**Table 11—Laboratory analysis of texture of four soils under Hawk's (1977) Swordfern Community in the valley of the South Fork Coquille River**

Site	Horizon	Depth	Sand/silt/ clay	Textural class <u>1/</u>
		cm	percent	
Ash Swamp <u>2/</u>	A1	0-8	45/20/35	CL
	A3	8-45	43/21/35	CL
	B	45-75	46/22/32	SaCL
	C	> 75	35/33/32	CL
Coquille River Falls Research Natural Area	A1	0-12	54/23/23	SaCL
	A3cn	12-26	50/24/26	SaCL
	B1cn	26-40	57/18/25	SaCL
	B3	40-95	47/25/28	SaCL
	C	> 95	60/23/17	SaL
Squaw Lake	A	0-10	66/18/16	SaL
	C	> 10	72/17/11	SaL
Port-Orford-Cedar Research Natural Area	A1	0-15	39/18/43	vgC
	B21t	15-45	34/15/51	vgC
	B22t	45-90	22/23/55	vgC
	C	> 90	20/25/55	vgC

1/ C = clay; L = loam; Sa = sandy; vg = very gravelly.

2/ Parent material of the first site was Quaternary alluvium; that of others was sedimentary rocks.

Source: Imper 1981.

Additional sites in Hawk's swordfern community in Coos County, OR, were analyzed in the laboratory for texture (table 11); they have a wider range of textures than Hawk's data indicate. Other brief soil descriptions of areas with Port-Orford-cedar are given for three Research Natural Areas in Oregon (Franklin and others 1972).

**Table 12—Occurrence of Port-Orford-cedar on land types identified in the Soil Resource Inventory, Siskiyou National Forest**

Bedrock type	Klamath Mountains			Total
	Siskiyou Mountains	Crest or east slope	West slope or north portion	
Gabbro and Metagabbro	<u>1</u> / 2/3	0/4	1/4	3/11
Dacite and Rhyolite			2/4	2/4
Ultramafic		0/5	4/4	4/9
Sandstones and Conglomerates	0/2		9/17	9/19
Colebrook Schist			2/2	2/2
Gneiss		1/3		1/3
Metavolcanics and Metasediments	3/3	0/4	4/5	7/12
Diorites and related rocks	- - -	4/5 - - -	4/4	8/9
Totals <u>2</u> /	9/13	5/21	26/40	

1/ Data are no. of types with the species/total no. of types.

2/ Port-Orford-cedar also occurs on land slump topography on all types of bedrock and on 6 of 10 landtypes on deep soils with mixed or undifferentiated origin.

Source: Meyer and Amaranthus 1979.

The Soil Resource Inventory for the Siskiyou National Forest (Meyer and Amaranthus 1979) includes a list of species that grow on each general soil type. Port-Orford-cedar is listed as present on 46 of 82 land types, although no indication of its importance is given. On the west slope of the Klamath Mountains and in the Oregon Coast Range at the north end of the forest, the species is more versatile (table 12) than on inland slopes. Some information contradicts Hawk (1977) and Whittaker (1960), who found the species inland on both ultramafic rocks and gabbro (it is not listed there in table 12). It is present on inland ultramafics, however, only where seepage is consistent—probably a very small proportion of the land type represented. Ultramafic soils in the northern Klamath Mountains have been described by Rai and others (1970).



**Table 13—Soil series that support >1 percent of the occurrences of Port-Orford-cedar, northern California Coast Ranges**

Rock type		Series name	Surface soil	
			Texture	pH
Serpentine	*	Dubakella	Gravelly-stony loam	Neutral
Ultrabasic igneous		Cornutt	Clay loam	Slightly acid
		Dubakella	Loam	Neutral
	*	Weitchpec	Gravelly-very gravelly loam	Moderately acid
Metamorphosed basic igneous		Boomer	Loam-gravelly loam	Slightly acid
	*	Hostler	Gravelly loam	Moderately acid
	*	Neuns	Gravelly sandy loam	Moderately acid
		(Unnamed)	Clay loam	Slightly acid
Schistose sedimentary		Josephine	Loam-gravelly loam	Slightly acid
	*	Masterson	Loam	Moderately acid
	*	Orick	Loam	Moderately acid
		Sheetiron	Gravelly loam	Moderately acid
Sandstone and shale	*	Hugo	Gravelly loam	Slightly acid
		Josephine	Loam	Slightly acid
		Melbourne	Loam	Moderately acid
Soft sedimentary rock		Mendocino	Loam	Moderately acid

\* = most consistently associated with Port-Orford-cedar.

Source: USDA Forest Service and others 1960-1962.

The Soil-Vegetation Maps of California (U.S. Department of Agriculture and others 1960-62) provide information about relative importance of various species on soil mapping units and briefly describe the soils for the area west of Hoopa Valley and along the lower Klamath River (table 13). In the Orleans Ranger District, Six Rivers National Forest, just to the east, Port-Orford-cedar is present on deeper phases of Hugo, Sheetiron, and Josephine soils, all on metamorphosed sediments of the Galice formation (Sawyer 1980, Sawyer and others 1977). On schistose and sedimentary parent materials in this area, Port-Orford-cedar is most common on soils of an intermediate degree of development (Hugo, Masterson, and Orick series, table 13) (Sawyer 1980, Zinke and Colwell 1965), which tend to occupy midslope positions. It also occurs, usually on lower slopes, on the little-developed Sheetiron and the better developed Josephine series. In this area, phosphorus concentration in subsoil is lowest on soils of an intermediate stage of development (Zinke and Colwell 1965)—those soils on which the cedar most often occurs.

Some lowland soils are described for coastal Curry (Buzzard and Bowsby 1970) and Josephine Counties, OR (USDA Soil Conservation Service and Oregon Agricultural Experiment Station 1972).

Port-Orford-cedar has been grown with varying success on several soil types in Europe (Boullard 1974, Camus 1914, Macdonald and others 1957, Schenck 1907, Zehetmayer 1954). Peat mixtures are suitable for growth of potted specimens (Besford and Deen 1977, Meneve and others 1971).

Port-Orford-cedar is considered to be a suitable tree to grow on 8 of 15 woodland soil groups in western Curry County, OR (Buzzard and Bowsby 1970), even though the tree is not common on these soils in southern Curry County. Suitable soils include those on marine terraces and on schistose and sedimentary bedrock (which cover 80 percent of the study area), those that range from 4.5 to 6.0 pH, and those with both shallow and deep water tables; included are Spodosols, Utisols, and Inceptisols.

**Chemical analysis.**—Chemical analyses are available for several soil types that support Port-Orford-cedar (table 14). They vary widely: pH ranges from strongly acid (on Blacklock soils) to neutral (Dubakella Series, table 13) with nutrient concentrations varying from eightfold to over 100-fold. Ultramafic soils have generally low nutrient levels (except for high levels of magnesium [Mg]) as do some other soils where cedar grows (table 14). Availability of nitrogen (N) in soils that support Port-Orford-cedar appears to be lower than in coastal soils farther north in Oregon (Imper and Zobel 1983, Plocher 1977). Cedar may, conversely, be excluded from some soils with low availability of Mg (Imper and Zobel 1983).

Chemical attributes of soils vary seasonally: pH varied by 0.4-0.8 units between September (highest) and January (lowest) (Imper 1981). pH of fine litter was 4.3 to 5.3 in July and about 0.4 units higher in January. Total N concentration in the surface mineral soil and concentrations of nitrate nitrogen ( $\text{NO}_3\text{-N}$ ) also varied with season.

Imper (1981) studied the form of N, the capacity of the soil to mineralize N, and other properties of soils under Port-Orford-cedar at five sites in the valley of the South Fork Coquille River. The moisture equivalent (which estimates the percent of water in the soil at field capacity) was 24 to 46 (median = 30); fine litter mass was 0.5 to 2.3 t/ha (for three plots); and loss on ignition (estimating percent of organic matter) was 9 to 19 percent (12) in July and 7 to 18 percent (10) in September. Total N in mineral soil (0-10 cm) ranged from 0.10 to 0.32 percent, with three plots not exceeding 0.15. Extractable ammonium nitrogen ( $\text{NH}_4\text{-N}$ ) in mineral soil was higher than  $\text{NO}_3\text{-N}$  by 1.7- to 17-fold, with  $\text{NH}_4\text{-N}$  varying from 2.2 to 4.1 p/m (parts per million) in July and 1.1 to 2.6 p/m in January; concentrations in the fine litter were 3-10 times higher. Both ammonium and nitrate in the soil declined from July to January. Incubations of soil and litter showed a range of response (table 15).

The capacity for N-mineralization of the topsoil was greater than that of the fine litter; however, per unit of dry weight, rates were higher in the litter. Mineralization was less in winter than in summer. Imper's (1981) sampling also illustrates that cedar distribution and soil properties vary with the microtopography within relatively small stands.

**Table 14—Soil chemical properties for surface mineral soils of Port-Orford-cedar stands or for soil types that support Port-Orford-cedar within their range (although probably not where sampled)**

Parent material	Type 1/	Number of stands	Reference 2/	pH	Cation exchange capacity	N	P	Extractable			Ca:Mg ratio
								K	Ca	Mg	
						percent	----- p/m -----	----- me/100 g -----			
Ultramafic	Stand	1	2	6.3	--	0.12	4	72	1.6	9.9	0.16
	Soil	3	4	5.8-7.0	10-42	--	3-8	22-149	1.0-8.0	1.1-29.0	0.09-2.3
				3/ (6.5)	(26)		(6)	(70)	(2.5)	(18.4)	(0.16)
	Soil	1	5	6.5	21	--	--	47	3.3	13.0	0.25
Basalt	Stand	1	1	--	--	--	--	50	.85	.42	2.0
Olivine gabbro	Soil	1	5	6.0	32	--	--	188	7.9	2.6	3.0
Quartz diorite	Soil	1	5	5.8	22	--	--	219	9.8	2.6	3.8
Eocene and Recent sedimentary	Stand	5	1	4/ 4.6-5.1		5/ .12-32	2-16	60-150	.7-10.6	.3-1.9	1.4-4.3
				(4.8)		(.14)	(8)	(130)	(2.0)	(1.0)	(2.5)
	Stand	1	2	5.2	--	.24	40	400	10.8	2.9	3.7
Jurassic sedimentary	Soil	1	6	5.1	31	.37	--	50	2.3	2.2	1.1
Marine sedimentary (Blacklock)	Stand	1	2	4.2	--	.09	26	36	.4	.36	1.1
	Soil	1	6	5.1	36	.52	--	75	3.2	1.2	2.7
Dune sand	Stand	1	2	5.1	--	.03	30	36	.3	.16	1.9
Mixed deep colluvium	Soil	6	3	5.2-6.0	21-40	--	43	40-456	4-13.9	.9-5.5	2.4-4.4
				(5.5)	(25)		(1 sample)	(55)	(10.5)	(4.3)	(2.6)
Several	Soil	5	3	4.9-6.4	22-33	.15-.17	7-77	36-490	1.2-15.9	.2-3.4	2.6-12.2
				(5.7)	(27)	(2 only)	(27)	(330)	(5.3)	(1.9)	(2.8)
Unspecified	Stand	5	7	4.8-5.5	--	--	12-75	--	.7-14.0	6/	--

-- = no data available; me/100 g = milliequivalents per 100 grams.

1/ Stand = sites with Port-orford-cedar; soil = soil types on which cedar grows in some areas.

2/ References are: 1--Imper and Zobel (1983) and Imper (1981); 2--Plocher (1977); 3--Meyer and Amaranthus (1979); 4--Rai and others (1970); 5--Whittaker (1960); 6--Buzzard and Bowsby (1970); 7--Siemens (1972).

3/ Values in parentheses are the median for the number of stands.

4/ pH values for September.

5/ Mean values for three sampling dates for N.

6/ "Very low" to "high."

**Table 15—Theoretical contribution of N-mineralization to the available nitrogen pool as ammonium or nitrate during incubation at 28 °C for 5 weeks**

(In grams per square meter)

Sample site	Fine litter	Top 10 cm of soil
Coquille River Falls		
Research Natural Area	0.11	1.9
Ash Swamp (sample 1)	.21	4.7
Ash Swamp (sample 2)	.38	12.3
Squaw Lake	.38	3.7
Port-Orford-Cedar		
Research Natural Area	ND	10.4

ND = not determined.

Source: Imper 1981.



**Table 16—pH of leaves, litter, and soil (averaged over the rooting depth) under Port-Orford-cedar and associated conifers in plantations in Great Britain**

Species	I pH of leaves and new litter	II pH at Bedgebury			III Soil pH		
		Fresh leaves	Litter	F + H layers 1/	Bedgebury	Gwydyr	Cirencester
Cupressaceae:							
Port-Orford-cedar	5.1	5.5	5.6	5.0	2/ 4.3	2/ 5.3	2/ 7.8
Western redcedar	5.1	5.5	5.4	4.8	4.3	5.1	7.7
Incense cedar	5.0	--	--	--	--	--	--
Pinaceae:							
Western hemlock	3.9	4.1	4.9	4.6	4.0	4.8	--
Douglas-fir	4.0-4.1	3.9	5.0	4.9	4.1	4.9	--
Grand fir and noble fir	--	--	--	--	--	4.9	--
Sitka spruce	--	--	--	--	--	--	7.4

-- = no data available.

1/ F + H = total of fermentation and humus layers.

2/ Includes Alaska-cedar in at least some plots.

Source: Column I--Handley 1954; II--Ovington 1953; III--Ovington and Madgwick 1957.

**Relationships to growth.**—Ten-year basal area growth in Imper's (1981) stands was related to 23 soil variables by regression analysis, after removing the effects of tree age. Growth of Port-Orford-cedar was significantly higher where nitrate concentration was higher ( $R^2 = 0.30$ ); in contrast, western redcedar grew faster where calcium concentration and clay content were higher ( $R^2 = 0.37$ ).

**Characteristics of litter.**—Although the forest floor is moderately shallow in most native cedar communities—1 to 4 cm (Hawk 1977)—Port-Orford-cedar may have distinct effects on soil properties because of its litter characteristics. Foliage and new litter of the cedar, along with other Cupressaceae, were the least acidic of several conifers in British plantations (table 16, sections I, II): This seems to be responsible for forest plantation soils developing the highest pH under Port-Orford-cedar (table 16, section III). The relatively low acidity of the litter and soil, in contrast to the high acidity under most Pinaceae, provides a reason for maintaining or introducing Port-Orford-cedar, or cupressaceous species in general, to managed stands.

Leaves and litter differ in other ways from those of associated conifers in British plantations (table 17): under Port-Orford-cedar, N is lowest and the carbon (C) to N ratio highest throughout the forest floor. Forest floor dry weight of Port-Orford-cedar and western redcedar was higher than for that under Douglas-fir and grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.).

Litter of Cupressaceae differs from that of the Pinaceae in structure. The litter under cedar is composed of branchlets, not leaves (Al-Sherifi 1952), that "retain their structure within the unincorporated organic matter but are broken into smaller distinct components below and hardly any amorphous humus is present" (Ovington 1954, p. 75). In contrast, litter of grand fir, Douglas-fir, and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) decomposes rapidly at first but decay slows later, resulting in a forest floor with a thin F-layer above a dominant H-layer (Ovington 1954).

**Table 17—Characteristics of fresh leaves and forest-floor layers of Port-Orford-cedar and associated conifers, 23- to 25-year-old British plantations**

Species	Forest floor weight			Nitrogen content			Ratio of C to N			Ash		
	Total	Percent in litter layer	Nitrogen	Fresh leaves	Litter layer	F+H 1/	Fresh leaves	Litter layer	F+H 1/	Fresh leaves	Litter layer	F+H 1/
	kg/na		kg/ha	- - - -	percent - - - -					- - - -	percent - - - -	
Port-Orford-cedar	12 893	17	152	0.92	0.84	1.24	67	70	39	4.6	8.4	24.6
Western redcedar	12 131	13	180	1.22	1.20	1.52	58	49	32	4.0	6.0	22.1
Western hemlock	12 160	63	188	1.48	1.20	1.76	40	48	26	3.5	8.3	26.1
Douglas-fir	10 931	24	156	1.27	1.29	1.46	48	44	27	4.7	20.3	36.2
Grand fir	6 592	28	--	--	--	--	--	--	--	--	--	--

-- = no data available.

1/ F + H = total of fermentation and humus layers.

Source: Ovington 1954.

#### Chapter 4: Forest Types Distribution Through Geologic Time

The fossil record for Cupressaceae is rich but hard to interpret because of difficulties identifying their leafy shoots. The genus *Chamaecyparis* seems to have been more widespread during the Tertiary than at present; it occurred in southern and central Europe and in western Asia between the Paleocene and the Pliocene (65 to 2 million years ago) (Florin 1963) and perhaps in western Europe in early Pleistocene (Huckerly and Oldfield 1976). The record of supposed *Chamaecyparis* fossils is most extensive in western North America (Axelrod 1976a, 1976b; Edwards 1983; Wolfe 1969) with the oldest found in the Eocene (50 to 52 million years ago) in Wyoming (MacGinitie 1974). Most interpretations (for example, Axelrod 1966, 1976a, 1976b; Robichaux and Taylor 1977) conclude that ancestors of Port-Orford-cedar dominated the North American record for the genus, although Wolfe (1969) dissents and identifies Alaska-cedar (*C. nootkatensis* [D. Don] Spach) from several locations in Nevada. An extensive, detailed study of foliar morphology of living and fossil Cupressaceae led Edwards (1983) to conclusions at variance with many earlier reports. He identified *Chamaecyparis* from about three dozen fossil locations in North America with deposits about 10 to 52 million years old. Several phylogenetic lines were suggested, one leading to Port-Orford-cedar and the related *C. linguaefolia* (Lesq.) MacGinitie at Florissant in central Colorado (MacGinitie 1953); one to Atlantic white-cedar (*C. thyoides* [L.] B.S.P.); but with the majority, including the widespread *C. cordillerae* Edwards & Schorn, being more closely related to Alaska-cedar. Fossils apparently ancestral to Port-Orford-cedar occur at Metzel Ranch (southwestern Montana, late Eocene); Gumboot Mountain and Lyons (northwestern Oregon, the latter 30 to 32 million years ago); Clarkia (northern Idaho, 14 million); Kilgore (north-central Nebraska, the easternmost *Chamaecyparis* location); Hidden Lake (northwestern Oregon, 13 million); and Trapper Creek (southeastern Idaho, 11-12 million) (Edwards 1983).

These populations are not associated with ultramafic substrates in most cases, but appear to have grown in streamside habitats (Edwards 1983). The associated climate had rainfall estimated at about 640-2030 mm (mostly 1010-1270 mm) and evenly distributed throughout the year. Paleotemperatures vary drastically with the method used to estimate them (Edwards 1983); however, the best estimates of mean annual temperatures are 7-12 °C, with mean annual ranges of 16-25 °C for taxa ancestral to Port-Orford-cedar. The lineage appears to have always been associated with relatively mild winter climates.

The fossil floras that include ancestors of Port-Orford-cedar differ from modern vegetation and vary substantially from place to place. Some forests had primarily broad-leaved species, and at two sites *Chamaecyparis* was the only conifer macrofossil; relatives of Alaska-cedar grew in more conifer-rich vegetation. The Hidden Lake flora, however, including taxa related to both Alaska-cedar and Port-Orford-cedar, contained the "most diverse conifer assemblage known in the history of the planet" (Edwards 1983, p. 198) with 16 genera. Comparisons of past and present ranges, environments, and associated taxa led Edwards (1983) to conclude that ecological tolerances have changed: The present ecological amplitude of Port-Orford-cedar reflects the concentration of genetically based characteristics in a small area that had developed in a much larger former geographic range.

In the range of Port-Orford-cedar, where there is relatively high humidity in the summer and a moderate range of temperature, conditions provided a refuge for mesophytic species beginning in the Pliocene (Axelrod 1976a, Whittaker 1961, Wolfe 1969). Port-Orford-cedar is considered a local but vigorous relict (Cain 1944). Pleistocene forests of the Klamath Mountains apparently occurred at lower elevations (Whittaker 1961); temperatures in northern California were 6-8 °C cooler and rainfall was considerably greater between 13,000 and 75,000 years ago than at present (Adam and West 1983). The interior California population of *Chamaecyparis* could be descendants of earlier interior stands, which spread out at lower elevations during cooler, moister climates, and reinvaded the high elevations after the last glacial retreat (see footnote 3); alternatively, the populations could have originated after the species migrated across the intervening low-elevation areas from the coast during the Pleistocene.

#### Forest Types and Their Distribution

With its small range and scattered distribution, Port-Orford-cedar is not usually considered in large-scale vegetation classifications. Kùchler's (1964) map of the United States lists it only for the southern part of his "spruce-cedar-hemlock forest"; for the map of California he includes it only for the northern part of the "redwood forest" and in the "mixed evergreen forest with chinquapin" (Kùchler 1977). It is recorded as a dominant in the Port-Orford-cedar forest cover type (Eyre 1980) and as present in the Sitka spruce, Pacific Douglas-fir, Redwood, Oregon white oak, and Douglas-fir-tanoak-Pacific madrone forest cover types.



Regional studies report Port-Orford-cedar in several vegetation zones. In Oregon, it grows in the "*Picea sitchensis* zone" and the "mixed evergreen zone," and its presence is used to define the "Port-Orford-cedar variant" of the "*Tsuga heterophylla* zone" by Franklin and Dyrness (1973). It is also a component of their "*Abies concolor* zone" (Hawk 1977, Atzet 1979). In southern Josephine County, OR, Atzet (1979) recognized a separate "*Chamaecyparis lawsoniana* Zone," which has been modified to a "*Chamaecyparis lawsoniana* series" following a more extensive sampling of southwestern Oregon.<sup>4</sup> In California, Port-Orford-cedar occurs in "redwood forest" (Zinke 1977), "mixed evergreen forest" (Sawyer and others 1977), and both the *Abies concolor* and *Abies magnifica* zones of the "Montane and subalpine forest" (Sawyer and Thronburgh 1977).

Several detailed vegetation analyses have been done in the range of Port-Orford-cedar. Hawk (1977) recognized eight major communities in well-developed cedar forests (tables 18 to 22). Characteristics of Port-Orford-cedar forests are discussed below, from north to south, based on the vegetation zone classification of Franklin and Dyrness (1973) and the communities recognized by Hawk (1977).

***Picea sitchensis* zone.**—The northern limit of Port-Orford-cedar seems to occur on coastal dunes, but landscape planting along the coast has been so general that the limit cannot be accurately located now. Boardman (1954) says the natural limit along U.S. Highway 101 was 13 km north of North Bend, which is near Hawk's (1977) Saunders Lake population on dry dunes. Port-Orford-cedar occurs in both dry and wet sand dunes (Egler 1934, Hawk 1977, Sargent 1881) along with shore pine (*Pinus contorta* Dougl. ex Loud. var. *contorta*), Douglas-fir, western hemlock (Hawk 1977), and typical dune associates (Egler 1934, Wiedemann and others 1969). It is not common in the dunes, however, and contrary to Sargent's (1896) "sea beach" statement, does not seem to grow well on the immediate coast. North of Coos Bay, the tree also grows profusely along roadsides and in stands off the dunes—stands apparently similar to those south of the bay. Some of the northern-most inland populations are limited to ridgetops and north-facing cliffs with open forests.

<sup>4</sup>Personal communication, 1981, T. Atzet, Area Ecologist, USDA Forest Service, Grants Pass, Oregon.

Table 18—Cover and diversity in eight major forest communities dominated by Port-Orford-cedar

		Cover by stratum 1/							
Zone	Community (number of plots)	Trees					Species per 375-m <sup>2</sup> plot		
		>15 cm d.b.h.	≤ 15 cm d.b.h.	Shrub	Herb	Moss	Trees	Shrub	Herb
		----- Percent -----					----- Number -----		
<u>Tsuga</u> <u>heterophylla</u>	Swordfern (13)	83	46	9	60	39	5	7	18
	Rhododendron (6)	84	33	91	24	40	5	9	13
	Beargrass (12)	85	30	30	25	45	5	6	11
Mixed evergreen	Tanoak (16)	80	37	97	8	19	5	11	14
	Mixed pine (11)	39	34	67	27	6	5	11	20
<u>Abies</u> <u>concolor</u>	White fir-hemlock (10)	86	30	50	16	7	7	10	16
	White fir (15)	77	37	40	20	1	5	10	27
	Mixed fir (15)	75	43	38	23	4	5	10	25

1/ "Tree cover" is an estimate for the whole layer; shrub, herb, and moss covers are totals for all species, counting overlapped areas for each overlapping species.

Source: Hawk 1977.

Table 19—Tree density, relative importance of Port-Orford-cedar, and size of Port-Orford-cedar in mature forests (>200 years) of eight major forest communities

Zone	Community and number of mature stands	Trees > 15 cm d.b.h.			Basal area		Conifer saplings and seedlings		Size of Port-Orford-Cedar	
		Total	Conifer	Port- Orford- cedar	Total	Port- Orford- cedar	Total	Port- Orford- cedar	Basal area per tree	Height at 300 years
		number per ha	percent	m <sup>2</sup> /ha	percent	number per ha	percent	m <sup>2</sup>	m	
<u>Tsuga</u> <u>heterophylla</u>	Swordfern (11)	342	304	38	121	63	2024	26	0.58	63
	Rhododendron (4)	313	313	63	144	47	1246	39	.34	53
	Beargrass (9)	497	485	55	150	68	1781	55	.37	31
Mixed evergreen	Tanoak (12)	389	371	74	150	60	2115	78	.31	44
	Mixed pine (3)	285	285	47	30	63	1867	24	.14	29
<u>Abies</u> <u>concolor</u>	White fir-hemlock (10)	464	415	48	83	55	1995	32	.21	41
	White fir (7)	674	670	82	139	63	4113	47	.16	46
	Mixed fir (12)	396	367	46	114	58	2207	37	.36	50

Source: Hawk 1977.

Table 20—Tree species and their degree of importance in the overstory and understory in eight major Port-Orford-cedar forest communities <sup>1/</sup> <sup>2/</sup>

Species	Zone:	<u>Tsuga heterophylla</u>			Mixed evergreen		<u>Abies concolor</u>		
	Community:	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed fir
<u>Abies concolor</u>		--	--	--	--	mo	Mou	Mou	Mou
<u>Abies grandis</u>		mou	mou	--	--	--	--	--	--
<u>Abies magnifica</u>									
var. <u>shastensis</u> <sup>3/</sup>		--	--	--	--	--	--	mou	mou
<u>Acer macrophyllum</u>		mu	mu	--	--	--	--	--	--
<u>Alnus rubra</u>		mu	mu	--	--	--	mu	--	--
<u>Arbutus menziesii</u>		--	mu	--	mu	mo	--	--	--
<u>Calocedrus decurrens</u>		--	--	--	--	mo	--	mo	mo
<u>Castanopsis chrysophylla</u>		--	--	--	mu	--	mu	--	mu
<u>Castanopsis sempervirens</u>		--	--	--	--	--	--	--	mu
<u>Chamaecyparis lawsoniana</u>		Mou	Mou	Mou	Mou	Mou	Mou	Mou	Mou
<u>Chamaecyparis nootkatensis</u>		--	--	--	--	--	--	--	mou
<u>Lithocarpus densiflora</u>		mu	mu	mu	Mou	mu	mu	mu	mu
<u>Picea breweriana</u>		--	--	--	--	mou	--	--	--
<u>Pinus attenuata</u>		--	--	--	--	mou	--	--	--
<u>Pinus jeffreyi</u>		--	--	--	--	Mou	--	mo	--
<u>Pinus lambertiana</u>		--	mo	--	mo	mu	mo	mo	mou
<u>Pinus monticola</u>		--	--	mo	mo	Mou	--	mo	--
<u>Pinus ponderosa</u>		--	--	--	--	Mou	--	mo	--
<u>Pseudotsuga menziesii</u>		Mo	Mo	Mo	Mou	Mou	Mo	Mo	Mo
<u>Quercus chrysolepis</u>		--	--	mu	mu	mu	--	mu	--
<u>Taxus brevifolia</u>		mu	mu	mu	mu	--	mu	mu	mu
<u>Thuja plicata</u>		mo	--	--	--	--	Mou	--	--
<u>Tsuga heterophylla</u>		Mou	Mou	Mou	--	--	Mou	--	--
<u>Tsuga mertensiana</u>		--	--	--	--	--	--	--	mo

-- = absent.

1/ M = major; m = minor; o = overstory; u = understory.

2/ Tree species associated in other vegetation types are Picea sitchensis, Pinus contorta, Quercus garryana, Q. kelloggii, and Sequoia sempervirens.

3/ Also considered to be A. procera by some authors.

Source: Hawk 1977.



Table 21—Major shrub species associated with Port-Orford-cedar in eight major forest communities<sup>1/</sup>

Species	Zone:	<u>Tsuga heterophylla</u>			Mixed evergreen		<u>Abies concolor</u>		
	Community:	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed f
<u>Acer circinatum</u>		--	M	--	--	--	--	--	--
<u>Alnus rhombifolia</u>		--	--	--	--	--	--	m	--
<u>Arctostaphylos nevadensis</u>		--	--	--	--	M	--	--	--
<u>Berberis nervosa</u>		m	M	m	m	--	m	m	M
<u>Castanopsis chrysophylla</u>		--	--	--	M	--	--	--	M
<u>Ceanothus pumilus</u>		--	--	--	--	M	--	--	--
<u>Corylus cornuta</u>		--	m	--	--	--	--	--	--
<u>Gaultheria ovatifolia</u>		--	--	--	--	--	--	m	m
<u>Gaultheria shallon</u>		m	M	M	M	--	--	--	--
<u>Holodiscus discolor</u>		--	m	--	--	m	--	M	--
<u>Leucothoe davisiae</u>		--	--	--	--	--	M	--	--
<u>Lithocarpus densiflora</u>		m	M	M	M	m	m	m	m
<u>Quercus sadleriana</u>		--	--	--	m	--	M	M	M
<u>Quercus vaccinifolia</u>		--	--	--	m	M	m	m	--
<u>Rhamnus californica</u>		--	--	--	m	M	--	--	--
<u>Rhododendron macrophyllum</u>		m	M	M	M	--	M	M	M
<u>Rhododendron occidentale</u>		--	--	m	M	M	--	M	--
<u>Rosa gymnocarpa</u>		--	m	m	m	m	m	m	m
<u>Umbellularia californica</u>		--	m	--	M	m	--	--	--
<u>Vaccinium membranaceum</u>		--	--	--	--	--	--	m	m
<u>Vaccinium ovatum</u>		m	M	M	M	--	--	--	--
<u>Vaccinium parvifolium</u>		m	m	m	m	M	m	m	M

-- = absent.

1/ M = major species ( $\geq 2$  percent cover); m = minor ( $\leq 2$  percent cover). Only species with  $\geq 2$  percent cover in at least one community are listed.

Source: Hawk 1977.

Table 22—Most important herbaceous species in eight major Port-Orford-cedar forest communities <sup>1/</sup>

Species	Zone:	<u>Tsuga heterophylla</u>			Mixed evergreen			<u>Abies concolor</u>	
	Community:	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed fir
<u>Chelys triphylla</u>		--	--	--	--	--	--	M	M
<u>denocaulon bicolor</u>		m	m	--	--	--	m	m	m
<u>nemone deltoidea</u>		m	--	--	--	--	--	m	m
<u>thyrium filix-femina</u>		--	m	--	--	--	--	m	m
<u>Technum spicant</u>		m	M	--	--	--	--	--	--
<u>arex serratodens</u>		--	--	--	m	m	--	--	--
<u>himaphila menziesii</u>		--	m	m	--	m	m	m	--
<u>himaphila umbellata</u>		--	m	m	m	--	m	m	m
<u>lintonia uniflora</u>		--	--	--	--	--	m	m	--
<u>lisporum hookeri</u>		m	m	m	m	--	m	m	m
<u>salium ambiguum</u>		--	--	m	m	m	--	--	--
<u>salium triflorum</u>		m	m	m	--	--	--	m	m
<u>woodyera oblongifolia</u>		m	m	m	m	m	m	m	m
<u>ris innominata</u>		--	--	m	m	m	--	m	--
<u>Innaea borealis</u>		m	--	m	m	--	M	M	M
<u>smorhiza chilensis</u>		--	--	--	--	--	--	m	m
<u>xalis oregana</u>		M	M	--	--	--	--	--	--
<u>polystichum munitum</u>		M	M	M	M	--	m	m	m
<u>teridium aquilinum</u>		m	m	--	m	--	m	m	m
<u>syntheris reniformis</u>		--	--	m	m	--	m	m	--
<u>fiarella unifoliata</u>		m	m	--	--	--	m	m	m
<u>rientalis latifolia</u>		m	m	m	m	m	m	m	m
<u>trillium ovatum</u>		m	m	m	m	--	m	m	m
<u>trillium rivale</u>		--	--	m	m	m	--	m	--
<u>vancouveria planipetala</u>									
or <u>V. hexandra</u>		m	m	m	m	--	--	m	m
<u>viola glabella</u>		--	--	--	--	--	--	m	m
<u>viola sempervirens</u>		M	m	m	m	--	--	m	m
<u>whipplea modesta</u>		m	m	m	m	m	m	m	--
<u>xerophyllum tenax</u>		--	--	M	m	M	m	M	--
Others		--	--	2/	--	2/	2/	2/	2/

<sup>1/</sup> M =  $\geq 1$  percent cover; m =  $\leq 1$  percent cover, -- = absent.

<sup>2/</sup> The following species occur only in one community: Beargrass: Coptis laciniata (m), Senecio bolanderi (m); Mixed pine: Festuca californica (M), Gentiana affinis (m), Horkelia sericata (m), Microseria nutans (m), Senecio canus (M), and Viola cuneatus (m); White fir-hemlock: Lysichiton americanum (m); White fir: Elymus glauca (M) Streptopus amplexifolius (m); Mixed fir: Pyrola secunda (m).

Source: Hawk 1977.

The best developed original forests of Port-Orford-cedar were near the coast in southern Coos and northern Curry Counties (fig. 8). Exploitation, major forest fires in 1867, 1868 (Hermann 1924, Sargent 1881), and 1936, and more recently, Port-Orford-cedar root rot, have apparently eliminated the old-growth forests. The first descriptions of these forests were by early travelers (Oregon Historical Records Survey 1942), by Beardsley (in Kellogg [1857]; also see appendix), and by Sargent (1881, summarized in 1884, 1896). On the hill behind Empire, on the west side of the peninsula south and west of Coos Bay, forests of Douglas-fir and Port-Orford-cedar had a thick, dense understory of *Rhododendron macrophyllum* up to 8 m tall. Near Marshfield, at the head of the bay, the forest

. . . is very dense and heavy, consisting of Douglas-fir, the western hemlock, *Thuya gigantea* [western redcedar], *Abies grandis* [grand fir], the 'Tide-water Spruce' [Sitka spruce], and Lawson's Cypress [Port-Orford-cedar]. It is the most beautiful forest we have seen. The undergrowth is very luxuriant. *Rhamnus Purshiana* is here a common tree, 40-50 feet high and over 1 foot in diameter. The *Rhododendron* has disappeared, but the Solomon Berry, the various *Vaccinia*, and the Roses, so characteristic of the Oregon forests, attain a size here we have not seen before. *Pteris aquilina* [*Pteridium aquilinum* (L.) Kuhn] reaches above our heads as we force our way through it. This forest gives a greater idea of productive capacity than any we have seen. No other coniferous forest on the continent compares with it in beauty, in grace, or in variety. Here Lawson's Cypress grows to a height of more than 150 feet, with a diameter of trunk of 8-10 feet. The trunks of these old trees are bare of branches for a great part of their height, and the heads are neither large nor very striking. The bark is remarkable on account of its thickness, being sometimes more than one foot thick on the old trees—a curiosity among the Cupressineae. . . .

The heaviest continuous body of Port-Orford-cedar is on Cape Gregory, extending south to and beyond the mouth of the Coquille [River]. This belt is about 20 miles long by an average width of 12 miles, and lies along the western slopes of the foothills of the coast range, extending within 3 miles of the coast. In this belt, two-thirds of the trees are cedar, the other Tidewater Spruce (*Picea sitchensis*), with a few Douglas-fir (Sargent 1881, p. 8).

The importance of cedar in these forests appears to have been considerably overestimated in the early descriptions, however (see cruise data presented on page 42 and in Chapter 8). This area is the low hills and uplifted marine terraces between the Coquille River-Coos Bay trough and the sea on primarily Coaledo formation sandstone and Quaternary alluvium and terrace deposits (Baldwin and others 1973); Sargent (1881) described the sites as "rather dry sandy ridges." Port-Orford-cedar was most abundant on the western slopes (Walling 1884). Old-growth forests were also present on river terraces (Dion 1938) and along the coast south to Port Orford in Curry County, where there were "immense white cedar forests so near the town" (Hermann 1924, p. 321).





Figure 8.—Old-growth Port-Orford-cedar forest in northern coastal Curry County, OR, 1911 (from American Lumberman 1911). The tree on the right is a Douglas-fir.

Many second-growth stands in this area burned in 1936 (Dion 1938), and root rot has decimated most of the rest. Port-Orford-cedar is present throughout much of this area, but the young forests have been little described. Cedar is not a major forest component near Blacklock Point in northern Curry County (Martin and Frenkel 1978), although it was a dominant just inland where the Curry County Airport is now located (Boardman 1954) on a Blacklock fine sandy loam (Buzzard and Bowsby 1970).

Hawk (1977) describes two communities of limited extent in this area. The "Sandstone" community is thought to be descended from the forests described by Sargent. It is dominated by Port-Orford-cedar and Sitka spruce (*Picea sitchensis* [Bong.] Carr.) with occasional Douglas-fir and western hemlock. The two 65-year-old plots sampled support little understory vegetation, although older forests resemble those in the swordfern community inland (except for presence of spruce). The "Blacklock" community occurs on uplifted marine terraces on the poorly drained Blacklock soil series with an iron hardpan (Jenny and others 1969). Port-Orford-cedar, western hemlock, and Sitka spruce are small and grow slowly; tree reproduction is dense, as is the shrub layer, which is dominated by evergreen huckleberry (*Vaccinium ovatum* Pursh), salal (*Gaultheria shallon* Pursh), and wax myrtle (*Myrica californica* Cham.) (Hawk 1977).

***Tsuga heterophylla* zone.**—Much of the present commercial forest lies within and bordering the drainages of the East Fork, the Middle Fork, and especially the South Fork Coquille River, south and inland from Coos Bay, OR. Three of Hawk's (1977) communities (tables 18 to 22) occur primarily in this area:

1. The swordfern community (*Tsuga heterophylla*-*Chamaecyparis lawsoniana*/*Polystichum munitum*-*Oxalis oregana* community of Hawk [1977]) occurs on the most productive sites sampled—the more mesic areas on sedimentary (mostly Eocene) rocks. Port-Orford-cedar and Douglas-fir dominate the overstory; western hemlock is abundant but the trees are small. Tree reproduction is common; it is dominated by western hemlock, and Port-Orford-cedar are plentiful. The shrub layer is the least important and the herbaceous layer the most important of all Port-Orford-cedar communities; the latter is dominated by swordfern (*Polystichum munitum* Kaulf. Presl.) and oxalis (*Oxalis oregana* Nutt.).
2. On less mesic sites on sedimentary rocks, the rhododendron community (*Tsuga heterophylla*-*Chamaecyparis lawsoniana*/*Rhododendron macrophyllum*-*Gaultheria shallon* community) occurs. Tree dominance is similar to the swordfern community, with Port-Orford-cedar, Douglas-fir, and western hemlock; conifer reproduction is much less dense and Douglas-fir is well represented along with the other two. The tall, dense shrub layer is dominated by rhododendron (*Rhododendron macrophyllum* G. Don) and salal and 10 percent of shrub cover is deciduous species. Herbaceous coverage, dominated by swordfern, is less than half that of the swordfern community.
3. The beargrass community (*Chamaecyparis lawsoniana*-*Tsuga heterophylla*/*Xerophyllum tenax* community) occurs on ultramafic rocks. The overstory is again dominated by Port-Orford-cedar, Douglas-fir, and western hemlock with some sugar pine (*Pinus lambertiana* Dougl.). Tree reproduction is primarily Port-Orford-cedar and western hemlock. The shrub layer is variable but the rhododendron is dominant. Beargrass (*Xerophyllum tenax* [Pursh] Nutt.) is the major herbaceous species. At higher elevations than those sampled by Hawk, western white pine (*Pinus monticola* Dougl. ex D. Don) can dominate the reproduction, and lodgepole pine is locally important.

Atzet (see footnote 4) recognizes one community (*Tsuga heterophylla*-*Chamaecyparis lawsoniana*/*Rhododendron macrophyllum*-*Gaultheria shallon*/*Polystichum munitum*) in his *Tsuga heterophylla* series, which appears to incorporate the three communities described above. Several other authors describe stands in the Coquille River drainage. Near the South Fork Coquille River, eight stands with Port-Orford-cedar, including six with western redcedar, can be classified in the swordfern community (Imper 1981). The association with western redcedar is not common, however. The Port-Orford-Cedar and Coquille River Falls Research Natural Areas include stands from all three communities (Franklin and others 1972, sections CO and PO). Contrary to Hawk's (1977) conclusion, Franklin and others (1972) state that western hemlock is reproducing much more effectively than is Port-Orford-cedar (see Chapter 6).

Other stands in the *Tsuga heterophylla* zone recur in and just east of the redwood belt in coastal northern California; these are a "Tsuga phase" of mixed evergreen forest (Sawyer and others 1977). Along the lower Klamath River, 16 percent of the vegetation units in which Port-Orford-cedar is the first or second most important species include hemlock, along with Douglas-fir and tanoak. Hemlock occurs with Port-Orford-cedar in many other stands (but not a majority) in the same area; all are on sedimentary and schistose sedimentary rocks (U.S. Department of Agriculture and others 1960-1962).

Port-Orford-cedar occasionally grows with redwood (*Sequoia sempervirens* [D. Don] Endl.) along the lower Klamath River (Hawk 1977, U.S. Department of Agriculture and others 1960-62) and Smith River (Hawk 1977, Zinke 1977), and their tributaries; Douglas-fir and western hemlock also occur in these stands.

**Mixed evergreen zone.**—Most low-elevation stands south of the Coquille River drainage and outside the range of redwood are in this zone in which broad-leaved evergreen trees are important. Two major communities are found (Hawk 1977), usually on ultramafic rocks (tables 18 to 22):

1. Tanoak community (*Chamaecyparis lawsoniana*/*Lithocarpus densiflora* community) occupies the more mesic locations. Port-Orford-cedar dominates both overstory and tree reproduction, with considerable Douglas-fir, tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and some pines. Shrub cover is almost complete; tanoak, salal, rhododendron, and azalea (*Rhododendron occidentale* [T. & G.] Gray) are all important. Herbaceous cover is the lowest of Hawk's communities at 8 percent.

2. Mixed pine community (*Pinus*-*Chamaecyparis lawsoniana*/*Quercus vaccinifolia*/*Xerophyllum tenax* community) occurs as open forest on less favorable sites. It occupies a large range of elevations but is most common in this zone. The open canopy is dominated by Port-Orford-cedar, with Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.) a distant second; Douglas-fir, western white pine, and sugar pine are common in some stands. Pines, Port-Orford-cedar, and Douglas-fir are all reproducing effectively. The understory is a mosaic of dense shrub clumps and open, herbaceous vegetation. The herb "phase" is more common on steeper slopes. Huckleberry oak (*Quercus vaccinifolia* Kell.) dominates the shrub layer with California coffee berry (*Rhamnus californica* Esch.) and, in the wettest spots, azalea being important. The major herb is beargrass.



Two mixed evergreen zone communities are more restricted (Hawk 1977):

1. The Douglas-fir terrace community (*Chamaecyparis lawsoniana*-*Pseudotsuga menziesii*/foothill alluvial terrace community) occurs along some large creeks above where they enter the interior valleys. These forests range from mesic, including deciduous red alder (*Alnus rubra* Bong.) and big leaf maple (*Acer macrophyllum* Pursh) in young forests, to relatively xeric with large tanoaks. Reproduction of Port-Orford-cedar, grand fir (*Abies grandis* [Dougl. ex D. Don] Lindl.), and Douglas-fir is common. Most shrubs are deciduous, which is unusual in this zone.

2. The meadow community (*Chamaecyparis lawsoniana*/ultramafic meadow community) is really azonal on ultramafic parent material in wet, open sites along streams or in bogs. Port-Orford-cedar is often the only tree in the wet areas. Shrubs and other trees are common only on drier hummocks or ridges. The herb layer is rich and dense, dominated by sedges, lilies, iris, and orchids. Cobra-plant (*Darlingtonia californica* Torr.) is common, and several other rare and endangered species grow in these sites. Well-developed examples of the community are Hunter Creek Bog and Snow Camp Meadow (Curry County, OR), and Woodcock Bog (Josephine County, OR).

Vegetation of this zone in Oregon has also been described by Whittaker (1954, 1960), Emmingham (1973), and Atzet (1979) (see page 37). In Atzet's more extensive classification (see footnote 4), the *Lithocarpus densiflora* series includes one community with substantial Port-Orford-cedar (*Lithocarpus densiflora*-*Chamaecyparis lawsoniana*/*Gaultheria shallon*-*Rhododendron macrophyllum*-*Vaccinium ovatum*). The cedar occasionally occurs in other communities of the series.

Similar forests occur in California within the range of Port-Orford-cedar. In the mixed evergreen forests of Klamath, Del Norte, and Siskiyou Counties, Port-Orford-cedar grow on the wettest sites in ravines on ultrabasic (= ultramafic), granitic, and metamorphic parent materials (Hawk 1977, Sawyer and others 1977, Zinke 1977).

Farther south, near Orleans, CA, Port-Orford-cedar is present on deeper soils of lower slopes on metasedimentary rocks of the Galice formation. At 200-700 m on deeper soils, Douglas-fir and Port-Orford-cedar dominate in mixture with evergreen hardwoods (Sawyer 1980). The shrubby understory is dense, but reproduction of all trees is occurring. Port-Orford-cedar is smaller and rare on shallow or rocky soils. In the northern Coast Ranges of California, Port-Orford-cedar is sometimes codominant with Douglas-fir and tanoak (Sawyer and others 1977) and sometimes with sugar pine (U.S. Department of Agriculture and others 1960-1962); on moister sites, western hemlock is also present.

***Abies concolor* zone.**—At high elevations south of the Coquille drainage, white fir (*Abies concolor* [Gord. & Glend.] Lindl. ex Hildebr.) is a primary, shade-tolerant conifer. Port-Orford-cedar dominates in three communities in this zone (tables 18 to 22) (Hawk 1977):

1. The white fir-hemlock community (*Abies concolor*-*Tsuga heterophylla*-*Chamaecyparis lawsoniana* community) is transitional between the *Tsuga heterophylla* and *Abies concolor* zones. Hawk (1977) describes it for the Silver Creek drainage in northwestern Josephine County, OR, where it occurs in ravines in a complex geologic area. Vegetation differs from any previously described, with western hemlock, white fir, and Port-Orford-cedar occurring together with Douglas-fir. All except Douglas-fir are reproducing effectively. The variable shrub layer is dominated by western leucothoe (*Leucothoe davisiae* Torr.). The herb layer is sparse.
2. The white fir community (*Abies concolor*-*Chamaecyparis lawsoniana*/herb community) is widespread on a variety of parent materials at high elevations in the southern two-thirds of the range. Port-Orford-cedar, Douglas-fir, and white fir dominate. White fir reproduction is less dense but more vigorous than Port-Orford-cedar reproduction. The shrub and herb layers are moderately well developed and diverse, and composition varies considerably.
3. The mixed fir community (*Abies*-*Chamaecyparis lawsoniana*/herb community) was sampled primarily on diorite in the upper Illinois River drainage in southern Josephine County, OR. Port-Orford-cedar dominates and Douglas-fir and white fir are common; Shasta red fir (*Abies magnifica* var. *shastensis* Lemm.) is often present. Tree reproduction is mostly white fir and Port-Orford-cedar with some Douglas-fir and Shasta red fir. The shrub layer is dense in young stands but decreases with age; herbaceous cover increases with age. The understory layers are diverse with no strong dominants.

Atzet's regional vegetation classification for southwestern Oregon (see footnote 4) recognizes two series in which both white fir and Port-Orford-cedar are important: (1) the *Chamaecyparis lawsoniana* series with four communities (*Chamaecyparis* /*Berberis nervosa*/*Achlys triphylla*, *Chamaecyparis*/*Berberis*/*Linnaea borealis*, *Chamaecyparis*/*Gaultheria shallon*/*Linnaea*, and *Chamaecyparis*/*Quercus vaccinifolia*/*Arctostaphylos nevadensis*); and (2) in two communities of the *Abies concolor* series where Port-Orford-cedar is usually present only in the understory.

The high-elevation Port-Orford-cedar communities in California are somewhat similar to those of southern Oregon (Sawyer and Thornburgh 1977). The tree is most common on ultrabasic rocks along with Douglas-fir and western white pine; this type is an upper elevation extension of the mixed evergreen communities. On other parent materials, the species is rare in the *Abies concolor* zone in California (Hawk 1977, Sawyer and Thornburgh 1977), and it is rare in open forests on rocky, damp moraines in the higher *Abies magnifica* zone of Sawyer and Thornburgh (1977).

**Table 23—Importance of Port-Orford-cedar in forests, Preston Peak-Clear Creek area, Siskiyou County, CA**

Forest type <u>1/</u>	Number of transects <u>2/</u>	Transects with Port-Orford-cedar	Mean			
			Cover		Relative density	
			Over <u>3/</u>	Under <u>3/</u>	Over <u>3/</u>	Under <u>3/</u>
			----- Percent -----			
Port-Orford-cedar	3	100	42	13	56	33
Port-Orford-cedar- Douglas-fir ecotone	2	100	25	2	46	6
Douglas-fir	21	57	6	2	11	5
White pine woodland	2	50	3	3	13	5
Sugar pine	5	40	2	1	7	1
Lodgepole pine	3	67	--	2	--	2
Weeping spruce	1	100	--	t <u>4/</u>	--	1

-- = absent.

1/ No Port-Orford-cedar were reported in single transects of the following forest types: weeping spruce-Douglas-fir ecotone; ponderosa pine, madrone-tanoak, Jeffrey pine, Douglas-fir-sugar pine ecotone; noble fir (*Abies procera*)-Douglas-fir ecotone; and noble fir. *Abies procera* is considered to be *A. magnifica* var. *shastensis* by some authors.

2/ Each transect line was 92-480 m long. Cover and relative density are averages for all transects where Port-Orford-cedar was present.

3/ "Over" and "under" refer to overstory and understory.

4/ t = < 0.5 percent.

Source: Siemens 1972.

Port-Orford-cedar forests in this zone are also described for the Brewer Spruce Research Natural Area (Franklin and others 1972, section BP) and for the Preston Peak area of northern California (Siemens 1972). In the Preston Peak area, Port-Orford-cedar dominates one type of montane forest. It is codominant with Douglas-fir on level sites along most stream drainages and there are a few extensive stands in basins (table 23). White fir may be common also. The understory is sparse. At higher elevations, between 1460 and 1770 m, Port-Orford-cedar grows with Alaska-cedar and western white pine.

The disjunct inland range of Port-Orford-cedar occurs primarily at high elevations (Hawk 1977, MacGinitie 1953; and footnote 5), although populations grow at least as low as 580 m along the Sacramento River in California. Near Cedar Lake, which is above 1700 m, the species grows in open, diverse forests that include Douglas-fir, white fir, mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.), five pine species, incense cedar, and a huckleberry oak understory. Port-Orford-cedar is most important, however, near lakes and streams in denser forests that have a diverse understory. Many plants from Hawk's (1977) meadow community are present. Port-Orford-cedar is reproducing effectively. In this area, it apparently reaches its maximum elevation of 1950 m (see footnote 1).

<sup>5</sup>Personal communications, 1981, R. Kelly, Berkeley, California, and J.O. Sawyer, Jr., Humboldt State University, Arcata, California.



**Table 24—Occurrence of Port-Orford-cedar in forest communities, upper Illinois River drainage, OR**

Zone	Community name and number of samples	Elevation <sup>1/</sup>	Total basal area	Port-Orford-cedar	
				Constancy	Cover
		meters	m <sup>2</sup> /ha	- - percent - -	
<u>Pinus jeffreyi</u>	<u>Pinus jeffreyi/Festuca rubra</u> (9)	920-940	58	22	9
<u>Chamaecyparis lawsoniana</u>	<u>Chamaecyparis lawsoniana/Gaultheria shallon/Linnaea borealis</u> (10) <sup>2/</sup>	540-1010	79	90	30
	<u>C. lawsoniana/Berberis nervosa/Chimaphila umbellata</u> (18) <sup>2/</sup>	1230-1440	100	78	9
	<u>C. lawsoniana/Quercus vaccinifolia/C. umbellata</u> (5) <sup>2/</sup>	1220-1560	77	80	23
<u>Abies concolor</u>	<u>Abies concolor/Berberis nervosa/C. umbellata</u> (9) <sup>2/</sup>	990-1370	86	67	23
	<u>A. concolor/Quercus sadleriana/C. umbellata</u> (18)	1480	81	6	t <sup>3/</sup>
	<u>A. concolor/Berberis nervosa/Achlys triphylla</u> (68)	1480	73	1	t <sup>3/</sup>

<sup>1/</sup> Elevation refers only to where the species was present.

<sup>2/</sup> Communities of the Chamaecyparis lawsoniana "group."

<sup>3/</sup> t = < 0.5 percent.

Source: Atzet 1979.

**Forest patterns in the Illinois Valley, OR.**—The montane forest vegetation of the Illinois River drainage has been described in detail using classification procedures for National Forest land (Atzet 1979, Emmingham 1973) and gradient analysis on three intrusive rock types (Whittaker 1954, 1960). In the valley along the lower Illinois River, Port-Orford-cedar is apparently quite rare and present only in moist, sheltered creek bottoms (Emmingham 1973). In the upper Illinois watershed, it is important in a variety of situations. Atzet (1979) recognizes a *Chamaecyparis lawsoniana* group of four communities, which includes 42 plots of the 250 ha surveyed (table 24). The first three communities constitute the *Chamaecyparis lawsoniana* zone where Port-Orford-cedar is reproducing effectively; in the fourth, white fir will at least share dominance at climax. Douglas-fir and white fir are significant; western white pine is scattered; Brewer spruce (*Picea breweriana* Wats.) is most common within the *Chamaecyparis* zone. Port-Orford-cedar forest grows primarily on protected, moist, midslope positions on northerly aspects on all parent materials (fig. 9), although it is relatively more common on ultramafics than are other forest types. Port-Orford-cedar often occurs in Atzet's (1979) *Pinus jeffreyi* zone on ultramafic rocks, with ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) and incense-cedar (*Libocedrus decurrens* Torr.). It is rare in other moist zones Atzet recognized and is absent from the xeric ones (table 24, fig. 9).

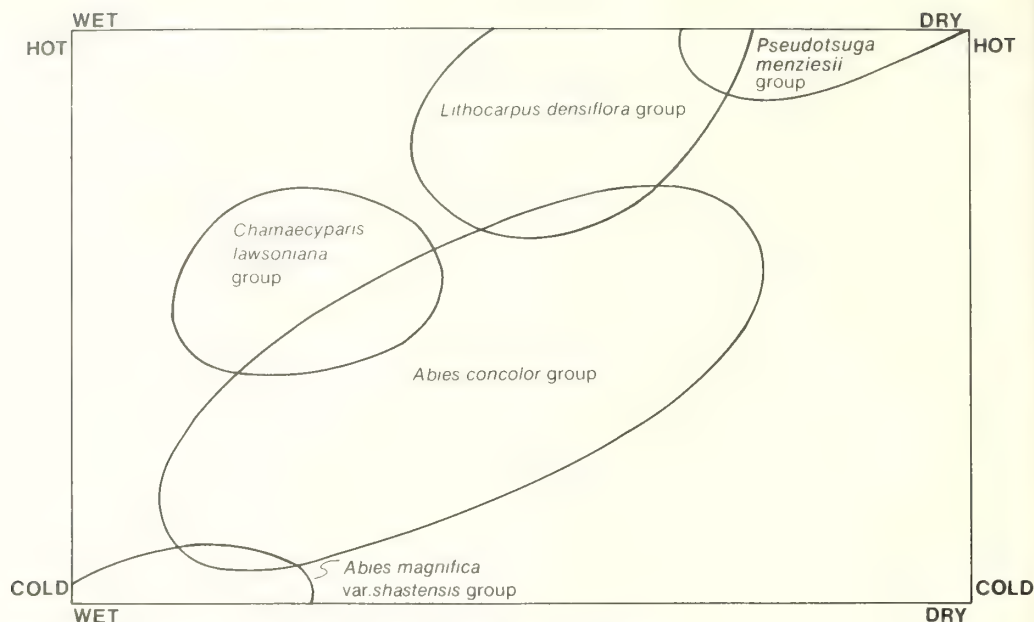


Figure 9.—Relative environmental position of the groups of forest communities, upper Illinois River drainage, Siskiyou National Forest (from Atzet 1979, fig. 67).

Whittaker's studies (1954, 1960) illustrate the gradient nature of the vegetation. His work emphasizes low elevations more than Atzet's does but is limited to ultramafics, gabbro, and diorite, the parent materials where Port-Orford-cedar is more important. The species is usually limited on all parent materials to the most mesic habitats, such as ravines with active streams and, sometimes, sheltered or northerly slopes; the habitat expands at high elevations and is widest on diorite (figs. 10 and 11, table 25). In all stands where reproduction occurs, Port-Orford-cedar is the most commonly reproducing conifer. It is most important above 760 m on diorite (table 26). On diorite the *Chamaecyparis-Pseudotsuga* forest has few sclerophylls and many deciduous trees. On gabbro, Port-Orford-cedar is less common and forests are more open; sugar pine, ponderosa pine, and incense-cedar are significant (fig. 12). On ultramafics, Port-Orford-cedar and western white pine share dominance (fig. 12); the cedar is dominant among the larger stems. Forests on ultramafics have the two-phased understory described for Hawk's (1977) mixed pine community.

**Discussion.**—Inconsistencies exist among the various descriptions of Port-Orford-cedar forest. Some may reflect differences in sampling strategy used by investigators. Hawk (1977) chose the best developed cedar forests, which are also the best developed of all forests throughout most of the range. Most other investigators sampled to represent the whole landscape. It is no wonder that Hawk's basal area values (see table 19) exceed those of Atzet (see table 24) for similar forest types.

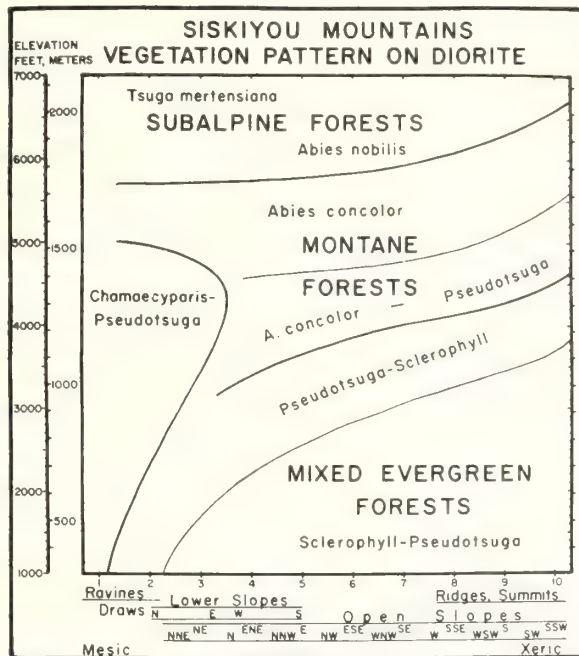


Figure 10.—Mosaic chart of vegetation on quartz diorite, central Siskiyou Mountains, OR. *Abies nobilis* = *A. magnifica* var. *shastensis* or *A. procera*. Numbers along the x-axis represent a gradient of wet (1) to dry (10) sites, as defined by topographic features listed below the figure (from Whittaker 1960, fig. 11, used courtesy of the Ecological Society of America, copyright © 1960).

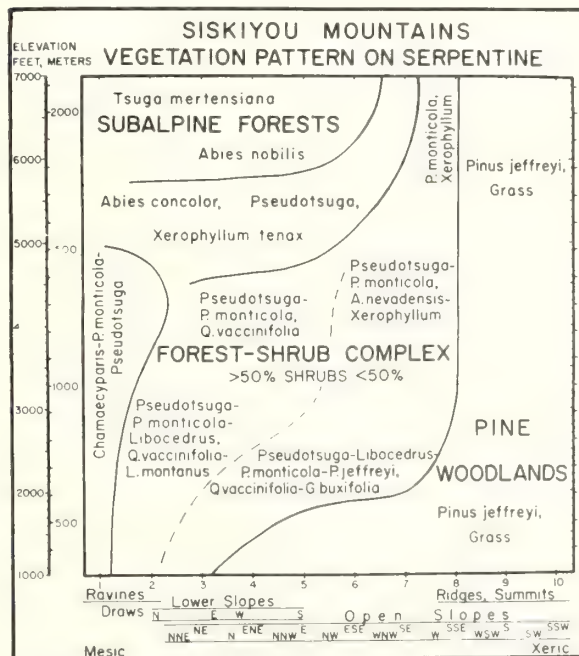


Figure 11.—Mosaic chart of vegetation on peridotite and serpentine, central Siskiyou Mountains, OR (*L. montanus* = *Lithocarpus densiflora* var. *echinoides*; *Libocedrus* = *Calocedrus*). Numbers along the x-axis represent a gradient of wet (1) to dry (10) sites, as defined by topographic features listed below the figure (from Whittaker 1960, fig. 12, used courtesy of the Ecological Society of America, copyright © 1960).



**Table 25—Occurrence of Port-Orford-cedar, by position, on the moisture gradient on three intrusive rocks at low elevations (610-915 m), Illinois River Valley, OR**

Rock type	Step on moisture gradient <u>1/</u>	Tree density		Port-Orford-cedar		
		All	Large only <u>2/</u>	All	Large only <u>2/</u>	Seedling frequency <u>3/</u>
		- - number/ha - - -		- - - percent - - -		
Diorite	1	810	136	25	40	2
	2	776	160	9	9	2
Olivine gabbro	1	850	34	20	35	4
	2	1496	38	1	21	--
Serpentine	1	838	272	37	72	6
	2	454	136	2	6	--
	4	542	88	1	2	--
	5	518	112	3	9	--

-- = absent.

1/ Whittaker recognized 10 steps of a complex, moisture-related gradient: 1 = most mesic, 10 = most xeric.

2/ Data are for trees > 37 cm d.b.h., except > 25 cm on serpentine.

3/ Number of 1-m<sup>2</sup> plots with cedar seedlings per thousand plots sampled.

Source: Whittaker 1960.

**Table 26—Occurrence of Port-Orford-cedar on diorite at four elevations, Illinois River Valley, OR**

Elevation	All trees > 1 cm	Port-Orford-cedar <u>1/</u>			
		Conifers > 37 cm	Trees > 1 cm	Conifers > 37 cm	Port-Orford-cedar seedling frequency <u>2/</u>
meters		- - number/ha - -	- - - percent - - -		
460-760	1669	87	1	10	2
760-1070	1031	140	10	24	13
1070-1370	518	183	17	17	7
1370-1680	523	199	14	12	9

1/ Importance of cedar as a percent of all trees (> 1 cm) and as a percent of large conifers (> 37 cm) in plots within each elevational segment.

2/ Number of 1-m<sup>2</sup> plots with cedar seedlings per thousand plots sampled.

Source: Whittaker 1960.

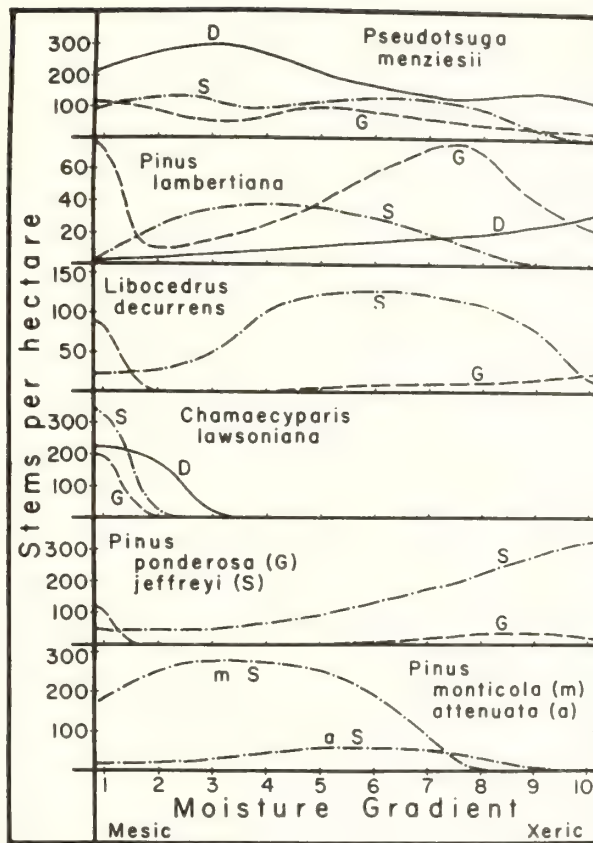


Figure 12.—Population distributions of conifers in relation to topographic moisture gradients at low elevations on diorite (D), gabbro (G), and serpentine (S) soils. Populations on diorite are represented by continuous lines; those on gabbro by broken lines; and those on serpentine by dot-and-dash lines (from Whittaker 1960, fig. 20, used courtesy of the Ecological Society of America, copyright © 1960).

A major inconsistency is between Whittaker's (1960, p. 316) emphasis on Port-Orford-cedar being a "parent material ubiquist" and Hawk's conclusion that it is limited primarily to ultramafic substrates at low elevations in the south. Several factors, besides differences in the precise areas sampled, seem to contribute to the different conclusions. Whittaker sampled only intrusive parent materials, on which the tree is apparently most important. At low elevations on diorite, the tree was considerably less common than at high elevations (table 26); furthermore, Hawk's sampling 25 years later required undisturbed, well-developed cedar forests, which remained on diorite only at high elevations. Hawk's sampling was also much less intensive in a given area than was that of most other investigators, and he did not sample the major low-elevation populations on sedimentary rocks in California. Our survey of the forest descriptions led us to conclude that the tree may occur on most rock types. At low elevations, Port-Orford-cedar forest occurs most consistently and is most common on (or near) ultramafic rocks. It grows well, however, on sedimentary rocks in the Coquille drainage and the lower Klamath drainage—in climates where western hemlock can grow.

**Table 27—Relative importance of Port-Orford-cedar in 16-ha units, coastal old-growth forest, Coos County, OR**

Total live timber volume per 16-ha unit		Port-Orford-cedar volume
<u>Cubic meters per hectare</u>		<u>Percent of total</u>
< 350 1/		38
350-700		11
700-1050		10
1050-1400		2
> 1400		1

1/ Recent burns.

Source: 1909-12 cruises of Beaver Hill Unit, Coos County Forest; provided by Ted Ellingsen, Coos County Forester.

#### Tree Composition of the Forest

Some data on tree composition are available from vegetation surveys (see tables 18, 20, 23, 24, 25, 26). As discussed above, values from these small, subjectively chosen plots may be much higher than are regional averages. Large-scale forest surveys of virgin Port-Orford-cedar forests exist for the Coos County Forest,<sup>6</sup> for the defunct Port-Orford-Cedar Experimental Forest in the drainage of the south fork of the Coquille River,<sup>7</sup> and the Bluff Creek project in the Six Rivers National Forest, 11-18 km west of Orleans, CA.<sup>8</sup>

Cruise data from 1909-1912 were available for about 220, 16.2-ha lots of old-growth forest in the Beaver Hill unit of the Coos County Forest. This area is about 15 km south of Marshfield (now Coos Bay). The average volume for all species was 1063 m<sup>3</sup>/ha, with the following composition: Sitka spruce, 57 percent; Douglas-fir, 34 percent; western hemlock, 5 percent; Port-Orford-cedar, 4 percent (a mean of 42.5 m<sup>3</sup>/ha); and a trace of western redcedar. The distribution of Port-Orford-cedar was spotty: it was absent from 43 percent of the units surveyed and was most important on recent burns (probably as survivors or dead merchantable timber) and in the less productive forests (table 27). Cedar was often most important on level, poorly drained topography.<sup>9</sup> The greatest estimated volume of cedar was about 530 m<sup>3</sup>/ha.

<sup>6</sup>Data on file, Coos County Forest, Coos County Courthouse, Coquille, Oregon.

<sup>7</sup>Data on file, Powers Ranger District, Powers, Oregon.

<sup>8</sup>Data on file, Orleans Ranger District, Orleans, California.

<sup>9</sup>Personal communication, 1981, Ted Ellingsen, Coos County Forest, Coquille, Oregon.



**Table 28—Average volumes of Port-Orford-cedar in old-growth forest in two areas, and maximal volumes for a section and for the smallest sampling unit reported**

Region and unit	Size of area	Volume of Port-Orford-cedar		
		Live	Dead	Total live volume
	ha	- - m <sup>3</sup> /ha - -		percent
Orleans District, CA (1940):				
Blue Lake	1/ 2979	2/ 24.3	1.7	--
Cappell Creek	T/ 1943	2/ 18.6	1.3	--
Highest section	T/ 259	2/ 47.1	5.6	--
Highest one-quarter section	1/ 65	2/ 96.0	11.3	--
Port-Orford-Cedar Experimental Forest, OR (1934-38):				
Experimental Forest	3752	86.0	9.3	26
Research Natural Area	459	117.0	6.2	20
Highest section	338	153.9	25.0	27
Highest lot	16	301.2	66.1	33

-- = total volumes not given.

1/ Precise areas not given; figures are estimated using the nominal size of a quarter section of 64.8 ha.

2/ Percentage of volume of trees in 36- to 66-cm diameter classes is 21, 26, 28, and 29, respectively. The remainder is larger trees.

In the Orleans study, volumes of large Port-Orford-cedar and selected other species were determined on two units in 1940 (table 28), and the concentration of Port-Orford-cedar was mapped for one of them. This is illustrated in part in figure 13. No information is available about the intensity of the cruise or the log rule employed. Several sections appear to be of nonstandard size which reduces the accuracy of the estimates.

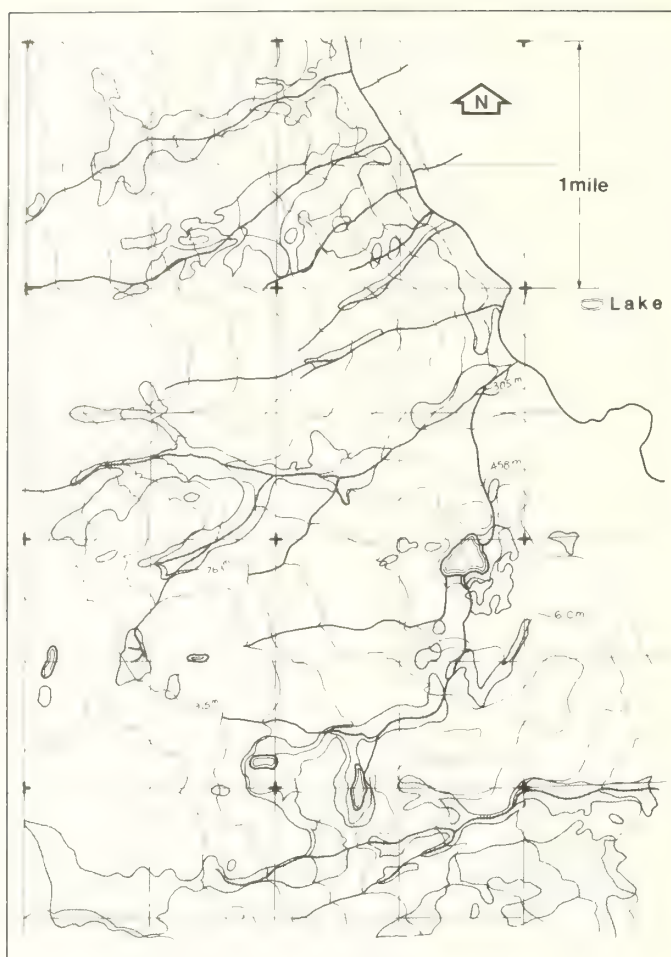


Figure 13.—Area southwest of Bluff Creek near Orleans, CA, showing the distribution of Port-Orford-cedar, which is important in the stippled area, in relation to topography. Light lines are contours, interval 250 feet (76.3 meters); heavy lines indicate streams. (Adapted from an unpublished map on file at the Orleans Ranger District, Orleans, CA.)

Volumes of timber in the Port-Orford-Cedar Experimental Forest (in the Coquille River drainage of Oregon) (table 28) greatly exceeded those in the Orleans district and the mean (but not maximum) volume in Coos County Forest. Volume of sound dead trees was significant in both areas. In the Experimental Forest, several forest types were recognized (table 29). Types varied in volume and composition. Port-Orford-cedar exceeded 40 percent of the volume over much of the area (fig. 14); however, Douglas-fir dominated most types. Other trees were usually insignificant, except for pines (table 30) on some ultramafic rocks. Tree density data reemphasize the dominance of Douglas-fir and Port-Orford-cedar (table 31), but their relative importance changed with the type of parent material. Douglas-fir averaged 463  $\text{m}^3/\text{ha}$  on sedimentary rock and only 46  $\text{m}^3/\text{ha}$  on ultramafic rock; corresponding volumes of Port-Orford-cedar were 175 and 107  $\text{m}^3/\text{ha}$ .

**Table 29—Definition of forest types recognized for the Port-Orford-Cedar Experimental Forest, 1935-37**

Type 1/	Volume of Port-Orford-cedar	Age	D.b.h. of dominant Douglas-fir	Age of Douglas-fir	Volume of sugar pine or western white pine
	Percent	Years	Centimeters		Percent
PC-A	> 40	> 150	--	--	--
PC-B	> 40	75-150	--	--	--
PC-D	> 40	< 75	--	--	--
PC-DA	20-40	--	> 102	Old growth	--
PC-DB	20-40	--	56-102	Old growth	--
DA	< 5	--	> 102	Old growth	--
DA-PC	5-19	--	> 102	Old growth	--
DB	< 5	--	56-102	Old growth	--
DB-PC	5-19	--	56-102	Old growth	--
DC	< 5	--	56-102	Second growth	--
DC-PC	5-19	--	56-102	Second growth	--
DD	< 5	--	15- 56	Second growth	--
DE	< 5	--	< 15	Second growth	--
P-PC-D (mature)	--	--	--	--	> 20
P-PC-D (immature)	--	--	--	--	> 20

-- = not applicable.

1/ PC = Port-Orford-cedar; D = Douglas-fir; P = pine. Last letter in series shows age with A being oldest and E the youngest.

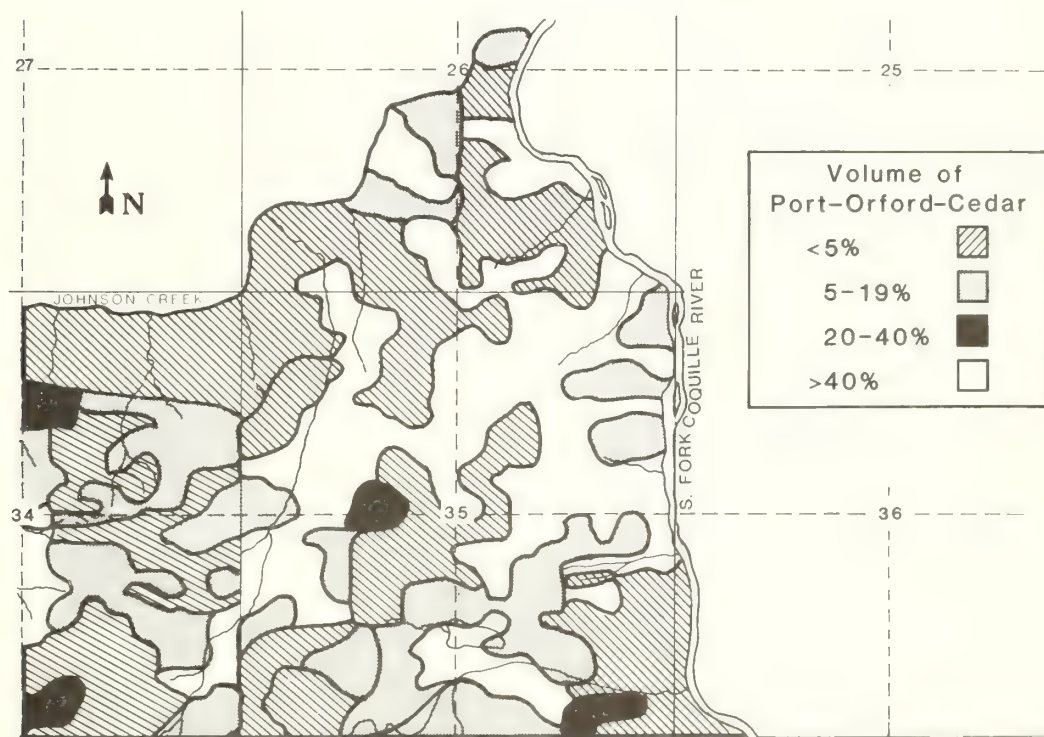


Figure 14.—Distribution of Port-Orford-cedar in the Port-Orford-cedar Research Natural Area, Coos County, OR, shown as a percentage of the total timber volume in 1935-38. Estimates based on a forest type map (types defined in table 29); additional information is in tables 28 and 30. Each large square with the number in the center is a 2.59 km<sup>2</sup> section. (From an unpublished map section on file at the Powers Ranger District, Powers, OR.)



**Table 30—Percentage of board foot volume, by species, in the Port-Orford-Cedar Research Natural Area and other portions of the Port-Orford-Cedar Experimental Forest <sup>1/</sup>**

Volume per species													
Forest type	Port-Orford-cedar												
	Total volume <sup>2/</sup>	Live	Dead	Douglas-fir	Western hemlock	Western redcedar	Incense cedar	Sugar pine	Western white pine	Grand fir	Deciduous hardwoods	Evergreen hardwoods	
	percent	m <sup>3</sup> /ha	percent	percent	percent	percent	percent	percent	percent	percent	percent	percent	
RESEARCH NATURAL AREA (459 ha)													
PC-A	7	568	54	2	37	3	--	--	--	3	1	--	
PC-B	1	143	59	14	24	--	--	2	--	--	--	1	
PC-DA	1	143	26	--	65	2	--	--	--	4	--	--	
JA	34	608	2	--	87	3	1	--	--	5	1	1	
DA-PC	21	841	13	1	81	2	1	--	--	1	--	1	
JB	7	271	2	1	96	--	--	--	--	--	--	1	
DB-PC	6	479	9	2	87	1	--	--	--	--	--	2	
REMAINDER OF EXPERIMENTAL FOREST (3293 ha)													
PC-A	1	55	55	6	29	4	--	2	3	--	--	--	
PC-DA	6	646	26	2	68	1	--	1	--	1	--	--	
PC-JB	1	306	25	1	62	6	--	6	--	--	--	--	
DA	7	604	2	1	93	1	--	1	--	1	--	--	
DA-PC	4	773	14	2	43	1	--	1	--	--	--	--	
JB	13	353	3	1	89	1	--	5	--	1	--	--	
DB-PC	1	484	16	1	81	1	--	2	--	--	--	--	
DD	1	32	3	49	28	--	--	--	1	13	2	5	
P-PC-D (mature)	12	157	10	1	35	2	--	1	48	4	--	1	
P-PC-D (immature)	4	25	33	10	21	--	--	9	26	--	--	--	

-- = absent.

<sup>1/</sup> Types with < 1 percent area are excluded; species are listed only where they comprise > 0.5 percent of volume.

<sup>2/</sup> Assuming m<sup>3</sup>/ha = 71.46 bd. ft./acre (Munns and others 1949).

Source: Unpublished data from a 10-20 percent cruise, 1935-37, on file at Powers Ranger District, Siskiyou National Forest, Powers, OR.

**Table 31—Size structure of conifer species on soils derived from sedimentary rocks on 664 ha, Port-Orford-Cedar Experimental Forest<sup>1/</sup>**

(In trees per hectare)

Conifers	Diameter				Dead
	15-29 cm	30-55 cm	56-105 cm	> 105 cm	
Total area:					
Port-Orford-cedar	4.3	<u>2/</u> 9.6(37)	<u>2/</u> 14.8(36)	<u>2/</u> 5.2(39)	2.3
Douglas-fir	--	12.8	24.3	8.1	--
Western hemlock	--	2.3	.5	0	--
Western redcedar	--	.1	.1	0	--
Sugar pine	--	.1	.2	0	--
Grand fir	--	1.1	1.3	0	1
16-ha lot:					
Port-Orford-cedar (maximum density)	13.6	22.8	26.6	13.6	7.6

-- = absent.

<sup>1/</sup> Major forest types, as defined in table 29, were PC-A (23 percent), PC-DA (18 percent), DB (14 percent), and DA (10 percent).

<sup>2/</sup> The percentage is shown in parentheses.

Source: Unpublished data from a 10-percent cruise in 1935 of Sec. 7, 18, and 19, T. 33 S., R. 11 W., on file at Powers Ranger District, Siskiyou National Forest, Powers, OR.

Comparisons among the cruise data sets are difficult. Because foresters change the merchantable diameter limits they use and the rules for judging defect, the older volumes may be only about half those produced by present day workers in the same timber (see footnote 9). To convert from board feet to cubic feet, a factor of 5 board feet per cubic foot was used (Munns and others 1949).

Stand volume data for natural young-growth stands are available only for the *Picea sitchensis* zone (table 32).

**Table 32—Density, basal area, and volume of natural, young-growth Port-Orford-cedar stands along the Oregon coast**

Location	Stand age	All species		Port-Orford-cedar				
		Density	Basal area	Stems	Basal area	Mean diameter	Mean height <sup>1/</sup>	Volume
	years	number/ha	m <sup>2</sup> /ha	percent		cm	meters	m <sup>3</sup> /ha
Coos County Forest	36	3361	68.4	60	60	16	16	244
	40	2817	71.6	48	50	18	16	205
	<sup>2/</sup> 65	1107	96.7	86	62	27	24	--
Coos-Curry County line	44	1853	93.7	81	70	24	22	506
	43	1705	79.9	81	64	22	22	445
Port Orford	61	1680	112.5	87	80	28	23	838
	57	1656	125.8	90	92	31	22	966

-- = absent.

<sup>1/</sup> Height of tree with mean basal area.

<sup>2/</sup> Data from two 375-m<sup>2</sup> plots of Hawk (1977).

Source: Primarily Hayes 1958.

#### Areas With Protected Port-Orford-Cedar Forests

Natural forests that include Port-Orford-cedar are found in five established and three proposed Research Natural Areas (table 33). Full descriptions of three of the established areas are given by Franklin and others (1972). The two largest Research Natural Areas are only 3 to 4 km apart and have had substantial mortality since about 1968 from root rot, especially in trees below roads and along drainages. Most of the sparse Port-Orford-cedar in the proposed Lemmingsworth Gulch Research Natural Area have already died from root rot.

The largest protected area where Port-Orford-cedar is found is the Kalmiopsis Wilderness Area. This is a 72 788-ha area at about 100-1400 m elevation in the Siskiyou National Forest, OR. Port-Orford-cedar is a minor part of the forest: the cedar can occur in concave sites throughout the area, but grows primarily in open forests on ultramafic rocks. Cedar in small numbers is also protected along with redwood in the Jedediah Smith Redwoods State Park, Del Norte County, CA. Well-developed stands occur in the proposed Siskiyou Mountain Wilderness Area in northwestern Siskiyou County, CA (Siemens 1972).

Stands having a more limited protected status also occur in a few hectares of the Port-Orford-Cedar Management Area, Happy Camp Ranger District, Klamath National Forest, Siskiyou County, CA, and in a larger area near Blue Lake, Orleans Ranger District, Six Rivers National Forest, Humboldt County, CA.

The major, and only explicit, formal protection of cedar stands occurred in 1937 and 1945 in two areas of Coos County. An effort to locate suitable Research Natural Areas in California was made in the late 1970's. Even if all the proposed Research Natural Areas are established, the actual area of cedar forest will be far below the 2000 ha suggested by Dion (1938), and much of it is in areas having a high risk of further depredation or infection by root rot. The forest types most poorly represented are those of major commercial importance; their representation will decline as root rot mortality continues to spread in Coos County.



**Table 33—Locations and characteristics of Research Natural Areas that have Port-Orford-cedar forests**

Name	County	Area	Elevation	Vegetation zone	Agency <sup>1/</sup>
		<u>Hectares</u>	<u>Meters</u>		
<b>Established areas:</b>					
Beatty Creek <sup>2/</sup>	Douglas, OR	70	365-610	Mixed evergreen	BLM
Brewer Spruce <sup>3/</sup>	Josephine, OR	169	1250-1665	<i>Abies concolor</i>	BLM
Coquille River Falls	Coos, OR	202	305-760	<i>Tsuga heterophylla</i>	FS
Port-Orford-cedar	Coos, OR	454	260-760	<i>Tsuga heterophylla</i>	FS
Woodcock Bog <sup>2/</sup>	Josephine, OR	45	455-825	Mixed evergreen	BLM
<b>Proposed areas:</b>					
Adorni	Humboldt, CA	ca. 243	185-730	Mixed evergreen	FS
Cedar Basin	Siskiyou, CA	ca. 400	1645-2120	<i>Abies concolor</i>	FS
Lemmingsworth Gulch <sup>2/</sup>	Curry, OR	484	335-830	Mixed evergreen	FS

<sup>1/</sup> BLM = Bureau of Land Management; FS = USDA Forest Service.

<sup>2/</sup> Port-Orford-cedar is not the major part of the value preserved in these Research Natural Areas. It is not in commercial quantity and is in a position particularly susceptible to infection by the root rot.

<sup>3/</sup> Also includes Alaska-cedar.

## Chapter 5: Characteristics of the Species Taxonomy

Port-Orford-cedar is classified as *Chamaecyparis lawsoniana* (A. Murr.) Parl., in the tribe Cupresseae (Li 1953), of the family Cupressaceae. Other common names are Lawson Cypress, Oregon-cedar, white cedar, ginger pine, and Port-Orford-white-cedar. The genus *Chamaecyparis* includes eight taxa, all found in coastal regions (Florin 1963) with six around the northern rim of the Pacific Ocean. Two species in Japan and two in Taiwan occur in temperate montane forests, similar in some ways to those where Port-Orford-cedar grows (Hawk 1977, Sato 1974). The other North American taxa differ considerably in their ecology: Alaska-cedar occurs in cold-temperate and subalpine forests, whereas Atlantic white-cedar grows in swamp forests along the Atlantic and Gulf Coasts of the United States. (The southern populations of *C. thyoides* are sometimes classified as *C. henryae* Li). Some authors (for example, Edwards 1983) include *Cupressus funebris* of central China in *Chamaecyparis*.

Port-Orford-cedar is the largest member of its genus, exceeding 60 m in height, 2 m in diameter, and 600 years in age. Its wood is rot resistant, has fine, uniform texture, straight grain, great dimensional stability, and is easily worked. Among the Cupressaceae, the tribe Cupresseae is distinguished by its spherical cones that bear 6-16 pairs of imbricated, thickened, shield-like scales (Li 1953). *Chamaecyparis* differs from *Cupressus*, the other American genus in the tribe, by its flattened branchlets and by having only 2-5 seeds per cone scale.

**Table 34—Differences in foliar and cone characteristics that are used to separate Port-Orford-cedar and Alaska-cedar**

Characteristic	Port-Orford-cedar	Alaska-cedar
Leaf length (millimeters)	1.5	3
Marginal vs. facial leaves	Marginal longer	Similar
Leaf glands	Obvious	Not obvious
Twigs	Flattened	Not flattened
Wax on protected leaf surfaces	Conspicuous	Little or none
Cone scale number	7 to 10	4 to 6
Cone scale projection	Present, but not prominent	Prominent

Source: Seven taxonomic manuals designed for use with natural populations.

Port-Orford-cedar occasionally grows with Alaska-cedar, and separating specimens can sometimes be difficult when using commonly cited morphological differences (table 34). Differences in leaf surface wax often disappear during drying of herbarium species. Relative length of facial and marginal leaves, "flatness" of the branchlets, and length of the outer protrusion of the cone scale intergrade between the species.<sup>10</sup> Presence of obvious leaf "glands" (pockets of resin just beneath the surface of facial leaves) on Port-Orford-cedar and its 7-10 cone scales seem more reliable for discriminating between the two cedars. Edwards (1983) provides a list of 20 potential taxonomic characteristics for foliage, seed, and cones that occur in field-grown plants.

Distinguishing Port-Orford-cedar without cones from incense-cedar and western redcedar may also be necessary in natural forests. Foliar differences among the three are usually quite distinct in the sun, but separating Port-Orford-cedar from western redcedar can be difficult in the shade. A useful characteristic in these cases is the distinct zig-zag nature of small western redcedar branches, a feature absent from Port-Orford-cedar.<sup>11</sup> Edwards (1983) provides detailed instructions for separating the three genera. Young seedlings of Port-Orford-cedar can be separated from associated conifers because they have only two cotyledons, each 5-10 mm long and flat in cross section, and they have juvenile needles with both surfaces being glaucous (Franklin 1961). Seedlings of Alaska-cedar continue to produce juvenile foliage long after Port-Orford-cedar seedlings growing under the same conditions have ceased.

<sup>10</sup>Data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.

<sup>11</sup>Personal communication, 1979, D.K. Imper, USDA Forest Service, Six Rivers National Forest, Eureka, California.

## General Characteristics Cupressaceae

Several characteristics of Port-Orford-cedar are typical for all Cupressaceae but are quite different from its major associates—Pinaceae. Some of the characteristics may be of considerable significance to the ecology. Mature leaves are small, scale-like, and appressed to the branchlet; the branchlets are shed as a unit. Masters (1891) suggests that small branchlets of Cupressaceae function analogously to leaves in Pinaceae. Unlike the Pinaceae, there are no bud scales and no preformation of a primary shoot that can rapidly elongate early in the following season.

As previously noted, the litter is less acidic than that produced by most Pinaceae, and Port-Orford-cedar has much thicker bark than most Cupressaceae, especially at the base of old trees. Bark thicknesses up to 25 cm have been reported (Sargent 1896).

## Shoot Development

Port-Orford-cedar develops three distinct types of leaves: cotyledons; similar but pointed primary (juvenile) leaves; and closely appressed, scale-like mature foliage (Daguillon 1899a, 1899b; Franklin 1961; Rouane 1973; Sudworth 1908). Figure 15 illustrates primary leaves and intermediate stages in development. The scale leaves occur in pairs, with alternate pairs oriented at right angles to each other. Facial leaves grow in the flattened portion of the branchlet; folded "lateral" or "marginal" leaves form the edges of the branchlet (fig. 16).

Leaf development and anatomy are described by Al-Sherifi (1952), Daguillon (1899a, 1899b), Edwards (1983), Fitting (1950), Masters (1891, 1896), Napp-Zinn (1966), and Oladele (1982) and stomatal distribution on the leaves by Florin (1931) and Zobel and others (1978). Changes in leaf structure during the progression from cotyledon to the scale leaf include: stomatal distribution changing from one to both faces of the leaves; appearance of a resin canal; increase in hypoderm tissue; greater cutinization of the epidermis; and greater development of the vascular bundle. The cuticle has small, cubical crystals, usually near the upper surface, with more on the abaxial side of the leaf (Al-Sherifi 1952, Oladele 1982).

Some leaf characteristics appear to retard water loss. The small leaves are closely appressed to the twig, and most stomata open into narrow clefts between the leaves. Stomata are more common on the adaxial surface. The guard cells are somewhat sunken. Accessory cells on the epidermis around the stomata have a wall-like protrusion around the outer stomatal chamber, and their surfaces have papillae composed of cutin, as in many other Cupressaceae. These protrusions from the epidermal surface are thought to reduce transpiration by Eurasian species of *Cupressus* and *Thuja* (Oppenheimer 1970). A layer of hypodermal fibers is common on the adaxial leaf surface. Transfusion tissue of the leaf, sometimes thought to affect leaf water relations, is simpler and less developed than in some conifers (Al-Sherifi 1952). The small leaf size of Port-Orford-cedar should theoretically be expected in saturated, as well as arid, habitats (Givnish 1978). The flattened branchlet has much higher surface-to-volume ratio, however, than do the round branchlets of Cupressaceae from arid climates. A cuticle thickness of  $5\ \mu$  is given for leaf surfaces of the "normal" form, but it varies between 4 and  $15\ \mu$  on four cultivated varieties (Napp-Zinn 1966).





Figure 15.—Seedlings of Port-Orford-cedar at the end of the first growing season in the greenhouse (from Franklin 1961, USFS Photo 498701).

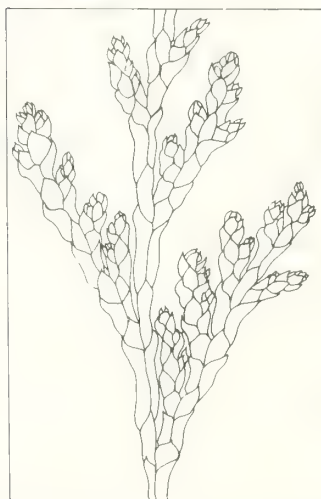


Figure 16.—A branchlet of Port-Orford-cedar, showing the facial and marginal leaves and the pattern of branching (from Rouane 1973, fig. 30, used courtesy Laboratoire Forestier de Toulouse).

Only 16 percent of the surface of scale leaves of nursery-grown seedlings bear stomata, with 56 and 60 stomata per square millimeter on facial and lateral leaves, respectively. The length of a stomatal pore is about  $25\ \mu$  (Camus [1914] cites  $35\text{--}40\ \mu$ ). Seedlings from sources in Coos County have more leaf surface bearing stomata and more stomata than seedlings from high-elevation Josephine County (Zobel and others 1978).

Leaf characteristics may vary even within a mature individual; for example, leaf characteristics change with branch order (Edwards 1983), and on rapidly growing shoots the distinction between facial and lateral scale leaves may be reduced or even disappear (Rouane 1973). Variability in foliage or branching characteristics, especially common with this species, has resulted in many useful horticultural varieties.

Branching occurs in the axils of lateral leaves only (see fig. 16). The pattern (Masters 1891, Rouane 1973) is relatively regular and leads to the frond-like character of Port-Orford-cedar foliage. Long shoots have longer internodes and fewer branches than do short shoots, but the two types are morphologically similar (Al-Sherifi 1952). Young seedlings have a branching interval of 1.4 cm and an upward angle and narrower crown than most species in the genus (Liu and others 1975). Treatment with gibberellic acid reduces branching but increases height growth (Bonnet-Masimbert 1971). The primary vascularization of the small branches is described by Lemoine-Sebastian (1971).

Development of the trunk of Port-Orford-cedar has been described only in a brief series of pictures (Hejnowicz 1967). Whether or not development is from a single meristem, as in most conifers, is not clear; "leader replacement" possibly occurs, as in some species of hemlock (Hibbs 1981).

The trunk often forks in both native and planted forests. In the native range this is not considered to be a significant problem, but in British plantations (planted at 2.4-m spacing) over half the trees forked below breast height (Macdonald and others 1957). Planting trees closer together reduced low forking by half. In Germany, forking was more common on drier soils (Schwappach 1911).

Because Port-Orford-cedar cultivars do not produce new branches from old wood, they have little capacity to recover from severe damage to the crown, such as deep killing by frost or excessive pruning (Welch 1966).

## Root System

The only detailed description of the root system of Port-Orford-cedar is for a dense, 50-year-old stand on a clay-loam soil in coastal Coos County (Gordon 1974, Gordon and Roth 1976). This stand had a very dense network of fibrous, absorbing roots at the surface that resulted from "humus strivers" (roots with unligified tips that grow up into the surface soil and duff). Humus strivers are produced uniformly along the length of the major horizontal system of surface roots. The number of major surface roots declined linearly away from the trunk, with 20 percent reaching 4 m. Beyond 4 m there was a slower decrease in root frequency, but only 0.6 percent of major roots extended beyond 6.7 m. Port-Orford-cedar has no tap root, but produces vertical sinkers from the horizontal system. Root systems of adjacent trees intermingle freely, with some overlap likely in trees closer than 12 m. Root

grafting between trees was common in the main horizontal surface root system, averaging 1.5 grafts per tree; the average graft was 34 cm deep between roots 3.8 cm in diameter. The chance of grafting decreased in a linear manner as horizontal distance between trees increased (becoming very small beyond 6 m) and with vertical distance on the slope. Graft complexes including several trees sometimes joined trees up to 12 m apart, however. Some root systems in a dense, windthrown, 39-year-old plantation north of the range had a surprisingly narrow extent, with a small root diameter where the roots had broken and almost no grafting.

In hydroponic culture, Port-Orford-cedar had a top-to-root dry weight ratio of 2.2 in full light, which was among the highest of eight conifers tested, and 3.0 in 10 percent of full light. This 1.3-fold increase occurred for three other species from the Pacific Northwest coast (including redwood and Douglas-fir); this increase contrasted to the twofold increase in conifers such as Jeffrey pine and incense-cedar, native to more southern areas (Baker 1945).

Root elongation increases at longer photoperiods and affects the tree's susceptibility to *Phytophthora cinnamomi* (Foster and others 1976). Root hairs do not form on Port-Orford-cedar in soil (Jones 1967); however, deviate root tip cells may resemble root hairs. Lateral roots of seedlings grow downward, in contrast to some conifers (Masters 1891). Information on the root apical meristem can be found in Pillai (1964).

## Chemistry

The chemistry of Port-Orford-cedar has not been described in much detail, but some aspects are of practical importance. The highly aromatic wood contains substances causing diuresis; sawmills cutting the cedar reportedly had to cut other species intermittently with the cedar to maintain the health of their workers (Sargent 1896).

The oil content of cedar apparently increases the wood's resistance to decay and termites (Carter and Smythe 1974) and is said to have insecticidal properties (Schenck 1912). The heartwood contains fewer compounds than do other Cupressaceae (Erdtman and Norin 1966), although it seems to have been less completely studied. Specifically, (-)- $\beta$ -bisabolene is the only sesquiterpene hydrocarbon identified; it contains cadinol, a cadinene; and the leaves produce the lignan deoxypodophyllotoxin. No tropolones have been identified from Port-Orford-cedar heartwood, although heartwood has a positive general test for their presence; Port-Orford-cedar lacks the nootkatin found in Alaska-cedar, and the thujaplicins that occur in incense-cedar and western redcedar (Zavarin and Anderson 1956). Pollen of Port-Orford-cedar, along with that of other Cupressaceae, is immunogenic in humans and may be allergenic (Yoo and others 1974). Seeds contain a substance that regulates insect growth (Jacobsen and others 1975). Tannins and mucilage occur in the pith and leaf mesophyll layer (Al-Sherifi 1952, Ersparmer 1953).



## Genetics and Variability

There is little information about genetics or natural patterns of variability of Port-Orford-cedar. In cultivation, however, it has produced a wider variety of stable horticultural forms than has any other conifer (Bean 1950) (also see next section).

The number of chromosomes in Port-Orford-cedar is  $n = 11$  (Munz and Keck 1959, citing Sax and Sax 1933), as it is for others in its family (Maeta and Yamamoto 1981, Sporne 1965).

Some recent studies in a common garden have measured variability among seedlings taken from sources in contrasting environments. Plocher (1977) found differences in growth and foliar nutrient concentrations for seedlings transplanted from different soil types in Coos County (see Chapter 6). Three studies in a Taiwanese nursery compared seedlings of coastal Coos County sources with those from high elevations in Josephine County. The coastal provenance had a higher percentage of the leaf surface with stomata and a (nonsignificantly) higher stomatal frequency (Zobel and others 1978); higher Ca and zinc (Zn) concentrations in foliage (Zobel and Liu 1979); but no consistent differences in leaf resistance to transpiration (Zobel and Liu 1980). Growth of cuttings from northern coastal trees was somewhat more than for cuttings from high elevations and from a source along the Sacramento River the first year, but not during the second (see table 51 and Zobel [1983]). Liu and others (1975), who used three seed lots of uncertain origin (including one cultivar), found some differences in early seedling morphology among sources. Compared to most Pinaceae, Port-Orford-cedar displays little genetic variation in timing of shoot elongation (Zobel 1983).

No provenance plantations have apparently been made (Macdonald and others 1957), although Boudru (1945) speculates that useful variability exists within the species. It may be that the potential of cedar in exotic plantations has been limited by the few original sources of seed used. The earliest seed collections were made along the Sacramento River, and because planted trees produced ample seed, seed was rarely imported into Europe after the potential of Port-Orford-cedar as a timber tree was recognized.

A few selections of "plus trees" and a few hectares of plantations from them have been made in Great Britain (Macdonald and others 1957).

## Cultivated Varieties

Port-Orford-cedar—usually referred to as Lawson cypress in cultivation—has produced a tremendous number of variants in size, branching and foliar habit, and in foliar color. This variety of forms has led to its status as one of the most popular and useful of horticultural conifers (Bean 1950, Dallimore and Jackson 1966, Harrison 1975). At least 220 cultivars have been developed (Rouane 1973), and 132 were still being used in 1965 (den Ouden and Boom 1965); however, only 50 or so are available for general cultivation (Harrison 1975). Most cultivars originated in Great Britain or The Netherlands, even most or all of the dozen or more formerly grown in Oregon (the most important being 'Allumii') (den Ouden and Boom 1965, Torgeson and others 1954). None are reported as being collected from natural populations and only 2 of the 205 listed by den Ouden and Boom (1965) originated in the United States. One shrubby form (originally *Cupressus attenuata* Gordon) was collected (Gordon 1875) but seems never to have been cultivated. At least one cultivar originated from the first seeds collected in California, which were planted in

Scotland in 1855. At least 27 forms were commercially available by 1875, some of which were developed in Europe (Gordon 1875). Introduction of new forms peaked in the 1890's and 1930's (den Ouden and Boom 1965, Krussman 1960), but new cultivars continue to be developed in Europe and in New Zealand and Australia (Harrison 1975, de Beer 1973). Some cultivars have remained popular for over a century. Of the 27 cultivars known to be available in 1875, 9 are among the 58 listed by Harrison (1975).

Most cultivars, especially the dwarf forms (Welch 1966), originated as seedlings, although rooting of "sports" on other plants has resulted in several new forms (seven listed by den Ouden and Boom [1965]).

Cultivars can be classified into several types. Krussman (1960) cites 67 with upright habit (34 with blue-green and silvery foliage, 22 yellow, 7 green, and 4 variegated); 15 as compact, broadly conical dwarf forms (9 blue-green, 4 green, 1 yellow-green, 1 variegated); 13 as dwarf and broadly hemispherical without a leader (6 blue-green and silvery, 3 green, 3 yellow, 1 variegated); 13 with drooping habit; 8 "curled"; 6 filiform; 4 with transition-form foliage; 3 prostrate; 2 short-stemmed; and 1 with juvenile-form foliage. A cultivar grown from seed and patented in 1973 (de Beer 1973) is distinctive for its combination of blue-gray color; winter hardiness to  $-30^{\circ}\text{C}$ ; compact, conical shape; needlelike, decussate leaves 3-6 mm long; and upright, dense branching.

Dwarfism can be extreme: One 1.2-m tall specimen of 'nana' is over 70 years old (Bean 1950). At least two forms of dwarfism occur: in 'minima' the trunk is absent or very small and the plant has several more or less equal, vertical main branches; in contrast, 'nana' always has a well-defined trunk and more horizontal branches. Growth rate can be controlled somewhat by the soil type. Most dwarf forms produce few or no seeds (Welch 1966).

Cultivars vary in resistance to cold (Day and Peace 1946, Duffield 1956, Harrison 1975, Welch 1966). Harrison (1975) cites 35 forms that are hardy at  $-24$  to  $-30^{\circ}\text{C}$ , 19 forms at  $-18$  to  $-24^{\circ}\text{C}$ , and 2 at  $-13$  to  $-18^{\circ}\text{C}$ . In general, the dwarf forms are less resistant to cold than are taller forms, and those with variegated or yellow foliage less resistant than green or bluish cultivars (Harrison 1975, Welch 1966). Cultivars also vary in susceptibility to *Phytophthora cinnamomi* (Torgeson 1953, Yates 1972), and in rooting capacity (see Chapter 6). Some of the color variation is attributable to differences in shading and soil (Welch 1966). The species can be easily shaped by pruning (Lamb 1938); however, pruning too deeply is detrimental as the species does not produce new branches from old wood (Welch 1966).

Many of the important characteristics of the ornamentals can be seen in natural populations. Perhaps the most obvious difference among native trees is in their color. Trees with bluish foliage occur throughout the range and variegated trees have been seen in Coos County. Differences in foliage form and branch angle (that is, drooping secondary branches) are also present. One difference among some cultivars (Welch 1966) is the relative length of the leading shoot of a branch and its laterals; similar differences occur among native trees. Shrub forms of the 'minima' type occur in open areas, most often on ultramafic soils; some natural shrubby plants have a much more open, sprawling nature.



## Hybridization

A morphological analysis of trees from two sympatric natural populations of Port-Orford-cedar and Alaska-cedar<sup>12</sup> revealed only one tree in northwestern Siskiyou County with definitely intermediate characteristics. Its leaves had resin pockets and waxy portions as Port-Orford-cedar does, but the twigs were much less flattened; its ratio of marginal to facial leaf length was intermediate; its cones had longer protrusions from the scales than most; and it had cones with 5, 6, 7, and 9 scales; many of the cones with 7 scales included scales that were incompletely separated.

A presumed hybrid (the cultivar 'nidiformis') of Port-Orford-cedar and Alaska-cedar was discovered at a nursery in Italy. The leaf structure of this shrubby cultivar is intermediate between the two species (Dallimore and Jackson 1966, Nicholson 1889), but den Ouden and Boom (1965) are skeptical of its hybrid origin.

Artificial hybrids with Atlantic white-cedar and the two Japanese species have been made (Maeta and Yamamoto 1981; Yamamoto 1981a, 1981b). Indices of the productivity of filled seed were calculated for the hybrids; 100 was the number assigned to crosses within the same species. Index values are given for Port-Orford-cedar as the female parent (the first number) and as male parent (the second number): 1.9/5.5 with Atlantic white-cedar, 29.4/(cross not made) with *C. pisifera* ([Sieb. & Zucc.] Endl.) (Sarawa cypress), and 18.1/0.2 with *C. obtusa* ([Sieb. & Zucc.] Endl.) (hinoki). However, 85 percent of seedlings from the Sarawa cypress cross lacked chlorophyll, and seeds of Atlantic white-cedar crosses were inviable. Germination and survival of hybrids with hinoki were better than for the pure Port-Orford-cedar tested, partially because of the hybrid's greater resistance to damping off.

Because other species of *Chamaecyparis* are immune or only slightly susceptible to *Phytophthora lateralis* Tuck. & J.A. Milb., hybridization may provide some potential for developing trees similar to Port-Orford-cedar that are less threatened by root rot.

## Wood Properties

Sapwood of Port-Orford-cedar is white, 2.5-8 cm thick, moist (200 percent), and often difficult to distinguish from the heartwood. It comprises 10-15 percent of a sample of second-growth bolts. Heartwood is creamy white, drier (40 percent moisture), and straight grained, with narrow rays and no resin canals. The narrow late-wood zone is only slightly denser than early wood. This uniform wood is easy to kiln dry and easy to work with, as it has little tendency to splinter when sawed or for the grain to tear when planed. When used for decking, it wears evenly without splintering. It is easily peeled on a veneer lathe. Tolerance of 0.05 mm can be maintained during machining. Knots are relatively small and tight. It is not liable to warp, is easy to glue, and takes a good polish. Along with other cedars and redwood, Port Orford cedar holds all common kinds of paints better than do most other woods. (This summary above is from Henley 1973, Laughnan 1959, Panshin and deZeeuw 1970, Port Orford Cedar Products Company 1929, Sargent 1885 and Stillinger 1953.)

<sup>12</sup>D.B. Zobel and K.M. Reynolds, unpublished manuscript, on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.



Wood from Port-Orford-cedar is moderately light in weight. Its specific gravity is 0.40 green and 0.44 oven dry (Panshin and deZeeuw 1970), although various other values have been given: 0.33 (Lavers 1969) to 0.47 (Port Orford Cedar Products Company 1929). Stillinger (1953) found a decrease in specific gravity away from the pith (0.400 to 0.381) and toward the top of the tree (0.406 to 0.345).

The straightness of the grain is emphasized by studies of dye movement: In Port-Orford-cedar and western redcedar, injected dye travels up the tree with little lateral movement and without the spiral path characteristic of many conifers (Vite and Rudinsky 1959).

The wood is stiff, moderately strong and hard, and moderately resistant to shock (Henley 1973). A reevaluation in 1972 of structural properties of Port-Orford-cedar wood produced values (table 35) higher than for western redcedar, sugar pine, and western white pine, which were sampled concurrently.

Strength properties of Port-Orford-cedar grown in New Zealand are similar to Douglas-fir grown there.<sup>13</sup> In sharp contrast, trees grown in Great Britain have wood that is lighter and much weaker than that from cedar grown in the United States, both in absolute terms and relative to western redcedar and other conifers (table 36). Some British authors also note that oiliness of Port-Orford-cedar wood tends to clog tools and the wood is difficult to smooth (Howard 1948), contrary to the information presented above. Wood grown in New Zealand is about as dense as that from the United States (Streets 1962). Port-Orford-cedar has relatively high rolling shear strength (2.24 N/mm<sup>2</sup>) (Bendtsen 1976). The elastic parameters for cedar wood have been calculated from other wood properties (Bodig and Goodman 1973).

Strength properties of second-growth trees in the United States are similar to those for old growth (Stillinger 1953). Among second-growth trees, a few properties varied with growth rate (fast growth,  $\leq 8$  rings per inch; slow growth,  $> 17$  rings per inch): shrinkage, the modulus of elasticity, and the modulus of rupture all were lower in fast-growing samples.

Port-Orford-cedar shrank 4.6 percent radially and 6.9 percent tangentially (10.1 percent in volume) during drying to zero moisture (Peck 1957); this was more than for other western Cupressaceae (6.8 to 9.2 percent) but intermediate among other western woods. An earlier estimate of shrinkage from green to oven dry was 5.2 percent radially and 8.1 percent tangentially (Port Orford Cedar Products Company 1929).

Although Henley (1973) cites a "high resistance to the action of acids" for Port-Orford-cedar wood, Ross' results (1956) indicate an intermediate position relative to 15 other conifer woods (13 western species). The average percentage of wet breaking strength retained after treatment was: 65 percent in 11 acid treatments, with other species varying from 60 to 70 percent (cedar being seventh highest of the 16 woods); 43 percent after exposure to five bases (range 37 to 56) (twelfth); and 89 percent in eight salt solutions (range 80 to 94) (sixth). It was relatively resistant to sodium hypochlorite—fourth most resistant of the species studied.

<sup>13</sup>Personal communication, 1982, B.P. Glass, New Zealand Forest Service, Rotorua, New Zealand.

**Table 35—Average specific gravity and mechanical properties of Port-Orford-cedar wood in a green moisture condition and at 12 percent moisture content for 33 randomly selected trees <sup>1/</sup> from throughout the range**

Attribute	Moisture content	
	Green	12 percent
Specific gravity	0.39	0.43
Static bending:		
Modulus of rupture (N/mm <sup>2</sup> ) <u>2/</u>	3/ 45.5	3/ 87.7
Modulus of elasticity (N/mm <sup>2</sup> )	8,945	11,717
Maximum crushing strength parallel to grain (N/mm <sup>2</sup> )	21.7	43.1
Maximum shear strength parallel to grain (N/mm <sup>2</sup> )	5.8	<u>3/</u> 9.4
Compression perpendicular to grain stress at proportional limit (N/mm <sup>2</sup> )	2.1	<u>3/</u> 4.9
Hardness (N): <u>4/</u>		
End	2,147	3/ 4,267
Side	1,698	<u>3/</u> 2,791

1/ Mean diameter, 48 cm; range of diameters, 26-61 cm.

2/ 1 N/mm<sup>2</sup> = 145.0 pounds of force per square inch.

3/ Values significantly different from values in the earlier literature. All values denoted thus are higher than earlier values except the modulus of elasticity.

4/ Load required to embed an 11.3-millimeter ball to one-half its diameter.

Source: Bendtsen 1972.

**Table 36—Strength properties of Port-Orford-cedar and other western conifers<sup>1/</sup>**

Species	Specific gravity	Static bending				Hardness 5/
		Maximum bending strength 2/	Stiffness 3/	Maximum compression strength 4/	Maximum shearing strength 4/	
		N/mm <sup>2</sup>				N 6/
Port-Orford-cedar	7/ 0.37	68	5400	28.7	10.8	2620
Western redcedar	.33	65	7000	35.0	8.5	2000
Douglas-fir	.44	91	10500	48.3	11.6	3420
Grand fir	.32	57	7000	30.1	7.7	1780
Noble fir	.33	63	8100	31.0	9.3	2000
Western hemlock	.38	76	8000	41.3	10.6	2580
Lodgepole pine	.42	79	8100	38.2	12.1	2940
Sitka spruce	.34	67	8100	36.1	8.7	2140

1/ All values are averages for wood from 5 to 54 trees grown in the United Kingdom, with 12-13 percent moisture content.

2/ Modulus of rupture.

3/ Modulus of elasticity.

4/ Parallel to grain.

5/ Resistance to indentation on side grain.

6/ N = 1 newton = 0.225 pounds of force.

7/ 0.33 using green volume.

Port-Orford-cedar wood has a distinctive, pungent, ginger-like odor, caused by a volatile oil. The odor in a Forest Service building that was constructed primarily of cedar is still intense after more than 40 years. Sawdust and mill residue yielded 1.6 percent oil in a commercial distillation (Thurber and Roll 1927) and stump heartwood, about 5 percent (Kritchevsky and Anderson 1955); the oil was analyzed by both authors. This oil may delay drying of paint but seems to prolong the life of the paint (Laughnan 1959). It also may cause skin rash and eye irritation. Prolonged exposure to the odor and fine sawdust affects kidney function (Henley 1973, Sargent 1881, Sudworth 1908), but the effect is not so pronounced as some early authors indicated (Thurber and Roll 1927).

Resistance to decay and to insects is high for Port-Orford-cedar wood (Henley 1973, Port Orford Cedar Products Company 1929). A sound log wrapped in the roots of 2.3-m diameter spruce was reported by Howard (1948). Untreated cedar pilings and posts remained sound after several decades in soil or exposed to tidewater, and cedar wood lasts well in mines, railroad tunnels, culverts, and ships. Trees killed by fire provide good lumber for decades (Peavy 1922). The wood is difficult to treat with preservatives (Macdonald and others 1957); in New Zealand this difficulty, plus only moderate durability of heartwood produced there, has limited the use of locally grown wood in construction (see footnote 13).

Port-Orford-cedar heartwood was more toxic to termites (*Reticulitermes flavipes* [Kollar]) than were 10 other woods, apparently because of its oil content (Carter and Smythe 1974). Termites will, however, attack weathered Port-Orford-cedar wood from which the oil presumably has been lost.



Its wood properties make Port-Orford-cedar a versatile material. They allow it to be used in traditional Japanese construction methods which use no fasteners, and its grain and color resemble hinoki (*Chamaecyparis obtusa*), the wood traditionally used in Japan: This accounts for its present high value on the export market. Port-Orford-cedar is the second-choice substitute (after the Taiwanese *Chamaecyparis*) for fulfilling the symbolic and structural functions of hinoki in Japan. Value of exported logs depends on fineness and evenness of the grain, absence of blemishes, and a less yellow color with some preference for more scent. Anything reducing the uniformity of the cut surface depresses the price. Value increases with log size; large logs allow more options for how the wood is cut and for matching color and grain. Wider panels can be cut. The wood properties that control the price of clear Port-Orford-cedar wood vary significantly within the range of the tree. Exports from near Powers, OR, have recently been most desirable, although some variation in preferences is reported among Japanese consumers.

The wood anatomy of Port-Orford-cedar (Bannan 1950, 1952; Greguss 1955; Panshin and deZeeuw 1970; Phillips 1941) varies within a tree and among trees. No single microscopic characteristic can be used to separate Port-Orford-cedar from Alaska-cedar or Atlantic white-cedar. Several details of ray anatomy used together are useful, however, for distinguishing species (Bannan 1952).

The average diameter of early wood tracheids is (radial x tangential, in  $\mu$ ) 33 x 26 in mature stems (Bannan 1952); it varies from 17 x 17 on the lower side of large branches to 41 x 29 in 1- to 3-cm roots. Bannan (1952) found no difference in tracheid diameter among species. In contrast, Panshin and deZeeuw (1970) list an average tracheid diameter of 34-45  $\mu$ , larger than Alaska-cedar and Atlantic white-cedar. Tracheid length increases outward from the pith in *Chamaecyparis* stems (1.3 to 3.2 mm) and branches (1.3 to 1.9 mm); tracheids are longest in the roots (4.4 mm) (Bannan 1950).

Port-Orford-cedar wood fibers from unbleached, unbeaten kraft pulp (Horn 1974), as compared to 11 other western woods, had low wood density (0.367 g/cm<sup>3</sup> of green volume), a short fiber length (2.98 mm), and small cross-sectional area (110  $\mu^2$ ), but a large length:thickness ratio (1,406). It also has a large number of fibers per gram (23.08 x 10<sup>5</sup>) and per cubic centimeter (15.23 x 10<sup>5</sup>) of pulp sheet; thin cell walls (2.12  $\mu$ ); low pulp fiber coarseness (15.0 mg/100 m); and a moderate fibril angle (8.5 degrees). Most characteristics were similar to Alaska-cedar and western redcedar, but quite different from Pinaceae. Port-Orford-cedar produced paper with moderate stretch, high tensile strength, a high burst factor, a low to moderate tear factor, and a high modulus of elasticity (Horn 1974).

The relatively small amount of literature on the autecology of Port-Orford-cedar has been reviewed by Minore (1979). Based on his summary, the species has the following characteristics (as compared to other conifers of the northwestern United States): moderate shade tolerance; fairly low drought tolerance; a moderately long period of shoot growth; a moderately young seed-bearing age; an average date of seed dissemination; a large seed crop size; moderately small seed; an average seed longevity; little stratification requirement for seed germination; and a high susceptibility to browse by rabbits and deer.

## Chapter 6: Autecology

## Water Relations

Insufficient water appears to be a very important factor limiting distribution of Port-Orford-cedar (Zobel and Hawk 1980). Several observations suggest the importance of water:

1. Port-Orford-cedar is limited to areas with relatively high ratios of precipitation to evaporation (p:e ratio), as noted in Chapter 2. It grows best as an exotic in similarly moist climates in Europe (Boullard 1974, Macdonald and others 1957).
2. Where the p:e ratio is highest, Port-Orford-cedar grows in dense forests on productive soils, with deep water tables on well-drained topography. In areas with a lower p:e ratio, the species is limited to less productive soils with shallow, persistent water tables, and lower density forest in concave topography (Hawk 1977, Sawyer and Thornburgh 1977, Zobel and Hawk 1980).
3. As climate has dried since the Eocene epoch, the range of Port-Orford-cedar has become restricted to an area with a high p:e ratio and equitable temperatures, similar to the climate in the early Tertiary period (Axelrod 1976a).
4. Water potential of Port-Orford-cedar saplings in late summer is rarely low. Average values are seldom below  $-9$  bars before dawn (all trees below  $-10$  bars are in the mixed evergreen zone); these values are less severe than those experienced by most competing conifers. Areas where the species occurs on drier soils are often near the coast where there is a persistent flow of moist air.
5. Local gradients of plant water potential exist at sites occupied by the cedar; local distribution ends where the most extreme predawn water potentials go below  $-11$  bars.
6. Along gradients of water potential, Port-Orford-cedar often drops out without other changes occurring in tree composition of the forest.

Soil moisture availability for Port-Orford-cedar is lowest in some terrace stands in the mixed evergreen zone (Zobel and Hawk 1980). Average predawn water potentials reached  $-20$  and  $-17$  bars at one site and  $-25$ ,  $-19$ , and  $-17$  at the other in 2 and 3 years of sampling, respectively. Some other environmental factor (or factors) must be highly favorable to allow the cedar to survive on these terraces. One possible compensating factor is recurring morning fog in the valleys (Atzet 1979); even so, these stands are a distinct exception to the usual relationship between Port-Orford-cedar and soil moisture.

Inference from the daily course of water potential suggests that Port-Orford-cedar can effectively control transpiration; daily reduction of sapling water potential was usually less, and midday water potential higher, than for Douglas-fir at the same location (Zobel and Hawk 1980).

The only measurements of leaf resistance to transpiration are for scale leaves on 1-year-old nursery seedlings in warm, well-watered conditions in Taiwan (Zobel and Liu 1980). Leaf resistance was low, the minimum for 5 days of measurement averaging 2.6 s/cm and the maximum, 5.2 (the mean was 4.2). Resistance, and its daily variability, were considerably less than for two Taiwanese *Chamaecyparis*. Some individual seed lots of Port-Orford-cedar produced seedlings with consistently high or low leaf resistance, but there was no consistent difference between averages of coastal and inland, high-elevation seed sources. Leaf resistance of Port-Orford-cedar was higher in January than in March and increased during the day and as the air dried. Sensitivity of Port-Orford-cedar to dry air was less than that of the Taiwanese species. There was no evidence of a threshold light intensity for stomatal closure. Resistance of Port-Orford-cedar trees in native environments must certainly exceed the resistance measured in Taiwan.

Several aspects of leaf morphology (Al-Sherifi 1952, Florin 1931, Napp-Zinn 1966, Zobel and others 1978), as described in Chapter 5, may affect water loss by Port-Orford-cedar. Even so, Port-Orford-cedar is not considered especially drought tolerant, as suggested by its distribution pattern. It is, however, considered more drought tolerant than western hemlock, Sitka spruce, and Shasta red fir, but less so than incense-cedar; Douglas-fir; grand and white fir; sugar, Jeffrey, and western white pines; and western redcedar (Minore 1979). Drying winds cause damage (Camus 1914). Extended drought may damage Port-Orford-cedar in its natural habitat (Sudworth 1908, Zobel and Hawk 1980) and elsewhere (Streets 1962, Thogo and Dyson 1974). A major drought in the natural range in 1976-77 damaged trees and reduced growth but only in the open forest where soil water potential had previously been drier than in most areas, or where temperatures were very high (Zobel and Hawk 1980). The effect of that drought was alleviated by a wet May.

Drought resistance may vary with the conditions of water supply. *Chamaecyparis obtusa*, for example, was more drought resistant than two other Japanese conifers when root penetration was limited, but was the least resistant species when seedlings had unrestricted rooting depth (Satoo 1956). If Port-Orford-cedar behaves similarly, this might help to explain its dominance on the shallow, rocky, and saturated soils it often occupies (Zobel and Hawk 1980).

Phenological traits that concentrate most growth processes in summer may be more consistently important than is susceptibility to drought in restricting Port-Orford-cedar to areas with ample and persistent water supply. Seeds did not germinate until mid-June in the one study in the natural range (Zobel 1980). A poorly protected apical meristem continues to divide, and leaves and internodes enlarge, producing new unhardened foliage later into the summer than do associated Pinaceae (see Vegetative Phenology section). Reproductive buds also develop through the summer (Hashizume 1973).

Port-Orford-cedar often grows in substrates that are saturated much or all of the year, where few other conifers survive. In the wet, ultramafic meadow community (Hawk 1977), it is the only tree in the wetter portions, even growing in and along the small streams. Although the water table fluctuates considerably in some areas in summer, in other cedar stands it is stable (Zobel and Hawk 1980).



Research in France (Levy 1973) indicates that other factors seem to override the effect of water table. Conifers were planted in soil having a high water table but which had been drained with three intensities of ditching, and on 50-cm ridges on the site. Port-Orford-cedar survived better (89 percent) on ridges than in any drainage treatment (60-72 percent) even though the water table was more shallow than in two of the three drainage conditions. Growth was also better on the ridges (after 2 years the height was 39 cm) than in the drained areas (24 to 31 cm). In contrast, survival and growth of Douglas-fir correlated well with water table depth. The authors do not know what factors controlled the behavior of the cedar. In the native range, areas with high water tables supporting Port-Orford-cedar have continuous water movement, not stagnation, as appeared to occur in Levy's (1973) study.

#### **Mycorrhizae, Tissue Nutrient Concentrations, and Growth**

As discussed in Chapter 3, Port-Orford-cedar grows naturally on a wide range of substrates, from very productive to very poor, with large differences in chemical properties. Growth rate and size of trees are correlated with these substrate differences, and differences in soil nutrient availability are a likely cause of variation in growth.

**Mycorrhizae.**—Port-Orford-cedar forms endomycorrhizae with fungi of the genera *Acaulospora*, *Gigaspora*, *Sclerocystis*, and *Glomus*. Most of the fungal symbionts grow on a wide range of hosts and habitats from moist coastal to inland arid climates (Gerdemann and Trappe 1974). Mycorrhizae collected from eight native stands with variable climate and substrate were all similar (Zobel and Hawk 1980). There seem to be no experimental studies of endomycorrhizal effects on growth of cedar; however, ectomycorrhizal fungi may influence growth or become symbiotic in some conditions (Levisohn 1953, 1954).

**Tissue nutrient concentrations.**—Nutrients are translocated to the leaves in the xylem sap. In the only study on composition of xylem sap, Port-Orford-cedar sap had a lower content of nitrogen than most conifers studied. No nitrate was found; most of the nitrogen was present in citrulline and glutamic acid, with smaller amounts of seven other amino acids. Citrulline was more important in Port-Orford-cedar than in the other gymnosperms studied (Bollard 1956, 1957).

The nutrient concentrations in foliage of Port-Orford-cedar vary considerably with the conditions of growth (tables 37 through 42). Native saplings showed significant differences in all macronutrients, iron (Fe), and boron (B) that are related to type of parent material (Zobel and Hawk 1980) (tables 37 and 38). On ultramafic substrates, N, P, and K were low, Mg was high, and the Ca:Mg ratio was low. Igneous rocks that were not ultramafic supported trees with high Ca and B and low Fe. Ca:Mg ratios were highest on other igneous rocks at high elevations. The pattern with field-collected seedlings (Plocher 1977) was similar; those from an ultramafic soil and from Blacklock soil on marine terrace sediments had the lowest concentrations of N, P, and K. In contrast, foliar nutrient concentrations of larger trees on productive soils near the northern end of the range were correlated with

Table 37—Macronutrient concentrations in foliage of natural trees of Port-Orford-cedar in its native range <sup>1/</sup>

Major substrate	Size	Sample date	Number of sites (trees/site)	N	P	K	Ca	Mg	Ca:Mg	S	Reference <sup>2/</sup>
----- Percent -----											
Sedimentary	Trees >15 cm	Sept.	3 (1-2)	1.38 (1.25-1.5)	0.16 (.15-.16)	0.94 (.88-1.00)	1.46 (1.46)	0.17 (.15-.19)	8.8 (7.7-9.1)	--	1
	Trees <15 cm	Sept.	6 (1-4)	1.23 (.90-1.85)	.14 (.11-.23)	.89 (.78-1.20)	1.30 (.83-1.86)	.16 (.11-.26)	8.4 (5.2-11.7)	--	1
	Saplings	Oct.-Nov.	3 (2-8)	1.01 (.89-1.14)	.13 (.12-.15)	.61 (.56-.69)	.90 (.50-1.20)	.18 (.11-.21)	5.0 (4.4-5.8)	--	4
	Seedlings	March	1 (15-20)	1.07	.20	.69	.60	.20	3.0	0.11	3
Basalt	Trees <15 cm	Sept.	1 (2)	1.31	.12	.67	1.34	.20	6.7	--	1
Ultramafic	Trees	October	1	0.93	.07	.40	.82	.40	2.1	.08	2
	Saplings	Oct.-Nov.	3 (10)	0.64 (.61-.67)	.07 (.06-.07)	.37 (.27-.42)	.90 (.83-1.00)	.30 (.24-.37)	3.2 (2.3-3.7)	--	4
	Seedlings	March	1 (15-20)	0.57	.09	.58	1.11	.30	3.7	.11	3
Jet sand dune	Seedlings	March	1 (15-20)	1.22	.21	.84	.54	.25	2.2	.19	3
Marine terrace sediments	Seedlings	March	1 (15-20)	.68	.09	.53	1.24	.11	11.3	.09	3
Diorite <sup>3/</sup>	Saplings	Oct.-Nov.	2 (10)	1.00 (.92-1.08)	.15 (.15)	.70 (.68-.71)	.98 (.88-1.08)	.21 (.12-.29)	6.2 (3.1-9.2)	--	4
Other igneous <sup>4/</sup>	Saplings	Oct.-Nov.	2 (10)	.94 (.78-1.09)	.11 (.09-.12)	.51 (0.51)	1.70 (1.37-2.02)	.27 (.17-.37)	7.7 (3.7-11.7)	--	4

-- = no data available.

<sup>1/</sup> Means are arranged by soil type and tree size; ranges of site means in parentheses.

<sup>2/</sup> References: 1--Imper and Zobel (1983); 2--David McNabb, unpublished data on file, Dept. of Forest Engineering, Oregon State University; 3--Plocher (1977); 4--Zobel and Hawk (1980).

<sup>3/</sup> One site included some ultramafic material.

<sup>4/</sup> Both sites may have included some ultramafic material.

Table 38—Micronutrient and aluminum concentrations in the foliage of native Port-Orford-cedar saplings on four substrates sampled in October and November

Major substrate	Number of sites	Trees per site	Mn <sup>1/</sup>	Fe <sup>1/</sup>	Cu <sup>1/</sup>	B <sup>1/</sup>	Zn <sup>1/</sup>	Al <sup>1/</sup>
----- Parts per million -----								
Sedimentary	3	2-8	423 (367-525)	254 (162-301)	7.3 (3.6-9.5)	18 (9-24)	55 (35-76)	226 (188-257)
Ultramafic	3	10	278 (178-400)	250 (214-308)	10.3 (7.0-13.6)	17 (14-20)	48 (42-54)	182 (124-286)
Diorite <sup>2/</sup>	2	10	389 (157-620)	176 (165-187)	11.6 (6.0-17.2)	29 (27-30)	43 (40-46)	193 (88-298)
Other igneous <sup>3/</sup>	2	10	626 (377-875)	113 (102-134)	4.7 (4.2-5.1)	29 (26-32)	50 (41-59)	122 (116-127)

<sup>1/</sup> Range of site means in parentheses.

<sup>2/</sup> One site included some ultramafic material.

<sup>3/</sup> Both sites may have included some ultramafic material.

Source: Zobel and Hawk 1980.

**Table 39—Macronutrient concentrations in whole seedlings of Port-Orford-cedar, 2 to 3 years old, grown in three nurseries, Washington and Oregon**  
(In percent)

Nursery	N	P	K	Ca
Greeley, WA	1.39	0.24	0.90	0.92
Wind River, WA	.57	.12	.74	.51
Corvallis, OR	.55	.12	.72	.53

Source: Youngberg 1958.

concentrations in the soil only when the soil content was low; overall correlations of foliar and soil concentrations were poor, with the best correlation being  $r = 0.41$  for P (Imper and Zobel 1983). The only reported foliar levels of nickel and chromium are 56 and 1.12 p/m, respectively, from an area with ultramafic rock.<sup>14</sup> Nutrient concentrations of cultivated seedlings may vary drastically with soil type (table 39).

To test the effects of soil type and seed source on growth, Plocher (1977) transplanted native seedlings reciprocally from four contrasting soil types in Coos County onto the same four soil types in the greenhouse. Foliar nutrient concentrations after 8 months were affected by soil type in the greenhouse for K, Ca, and Mg, and by the source of the seedlings for all macronutrients except sulfur (tables 40 and 41). The most obvious effects of soil type were the high foliar K on sedimentary soils and the low Ca, high Mg, and low Ca:Mg ratio on ultramafic soils. The population most consistently different was from a wet dune and had relatively high values of foliar N, P, and K, a low Ca concentration, and a low Ca:Mg ratio (table 40).

Foliar nutrient values of seedlings grown in Taiwanese nurseries differed less among populations than in Plocher's work (Zobel and Liu 1979). Seedlings from four coastal seed trees had higher Ca and Zn in the leaves than did those from four seed trees on ultramafic soils (table 42); other nutrients were similar. There were no differences among trees within either of the two source areas; however, the nursery-grown seedlings differed in several ways from native populations growing in the regions where the seed came from (table 42).

Twenty-year-old planted trees at Bedgebury, England, had foliar nutrient values (in percent) of 0.92 N, 0.06 P, 0.30 K, 1.02 Ca, 0.19 Mg, and (in parts per million) of 140 Fe, 9900 manganese (Mn), and 300 sodium (Na) (Ovington 1956). Compared to native trees on sedimentary soils (tables 36 and 37), values of N, P, K, and Fe were all low, and Mn was extremely high.

<sup>14</sup>Unpublished data of D. McNabb, on file at Department of Forest Engineering, Oregon State University, Corvallis.



**Table 40—Concentrations of macronutrients in foliage of natural seedlings collected from four soil types, Coos County, OR, reciprocally transplanted to field-collected soils, and grown for 8 months in a greenhouse <sup>1/</sup>**

Population	Soil			
	Sedimentary	Dune	Ultramafic	Blacklock
Nitrogen (percent)				
Sedimentary	1.04	1.02	0.93	0.93
Dune	1.14	.97	.98	--
Ultramafic	1.02	.67	.88	--
Blacklock	.92	1.23	1.07	1.13
Phosphorus (percent)				
Sedimentary	.27	.33	.24	.15
Dune	.32	.35	.31	--
Ultramafic	.28	.19	.25	--
Blacklock	.24	.33	.29	.14
Potassium (percent)				
Sedimentary	1.05	.85	.88	.83
Dune	1.28	.91	.99	--
Ultramafic	1.11	.63	.89	--
Blacklock	1.15	.68	.91	.84
Calcium (percent)				
Sedimentary	.65	.59	.39	.70
Dune	.58	.52	.32	--
Ultramafic	.65	.68	.38	--
Blacklock	.62	.68	.38	.71
Magnesium (percent)				
Sedimentary	.17	.25	.50	.17
Dune	.19	.29	.48	--
Ultramafic	.21	.25	.48	--
Blacklock	.18	.32	.49	.22
Ca:Mg ratio				
Sedimentary	3.7	2.4	.8	4.1
Dune	3.0	1.6	.7	--
Ultramafic	3.2	2.4	.8	--
Blacklock	3.5	2.7	.8	3.2

-- = no data.

1/ Foliar sulfur concentrations varied from 0.04 to 0.26 percent. "Blacklock" soils developed on marine terrace deposits and support only slow growth. Significance of population and soil is given in table 41.

Source: Plocher 1977.

**Table 41—Significance of population and soil type in affecting foliar nutrient concentrations of Port-Orford-cedar seedlings collected in the field and grown on three field soils in the greenhouse<sup>1/</sup>**

Nutrient	Source of variation		
	Soil	Population	Soil x population
Nitrogen	NS	**	**
Phosphorus	NS	**	**
Potassium	**	**	**
Calcium	**	**	NS
Magnesium	**	*	**
Sulfur	NS	NS	NS

NS = not significant; \* = significant at 0.05 level; \*\* = significant at 0.01 level.

<sup>1/</sup> Data are in table 40. Results from Blacklock soil were not included in the statistical analysis.

Source: Plocher 1977.

**Table 42—Nutrient concentrations, as sampled in July, in 17-month-old nursery seedlings of Port-Orford-cedar grown in Taiwan**

Source <sup>1/</sup>	N	P	K	Ca	Mg	Ca:Mg	Mn	Fu	Cu	B	Zn	Al
----- Percent -----												
Nursery Seedlings:							----- Parts per million -----					
Low elevation-- Coastal (Coos County)	1.69 (1.61-1.82)	0.35 (.32-.40)	0.54 (.49-.58)	0.62 (.60-.65)	0.17 (.16-.18)	3.6 (3.4-4.1)	745 (605-854)	766 (620-909)	19 (16-23)	14 (12-16)	120 (117-124)	780 (622-927)
High elevation-- Interior (Jose- phine County)	1.70 (1.60-1.83)	.33 (.25-.37)	.64 (.55-.75)	.55 (.51-.59)	.16 (.14-.21)	3.6 (3.0-3.9)	685 (616-800)	687 (449-1428)	19 (13-27)	15 (13-18)	102 (88-112)	817 (418-1317)
Native saplings 2/:												
Coos Co. Forest	1.14	.12	.68	.50	.11	4.4	367	162	3.6	9	76	188
Grayback <sup>3/</sup>	.92	.15	.71	1.08	.12	9.2	620	187	17.2	27	46	298

<sup>1/</sup> Each seed source included seedlings from four seed-trees; the range of seed-tree values is given in parentheses. The only significant differences between sources are for Ca and Zn.

<sup>2/</sup> Data for native saplings in the areas where seed was collected are given for comparison.

<sup>3/</sup> Grayback is near the Josephine County seed source.

Source: Unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis; and Zobel and Liu (1979).

Foliar nutrients of potted plants can be quite different from those of forest trees. The cultivar 'Columnaris' in three fertilizer treatments (Besford and Deen 1977) had values (in percent) of 2.65-3.77 N, 0.46-0.51 P, and 1.43-1.93 K; all are higher than any for native or nursery plants (tables 37 and 39). In contrast, the cultivar 'Pottenii' has values for N, P, and K that are similar to nursery seedlings.

Port-Orford-cedar usually has lower foliar concentrations of all macronutrients than the Taiwanese species of *Chamaecyparis* grown in the same nursery, but higher Zn and aluminum (Al) (Zobel and Liu 1979). Native trees of Port-Orford-cedar have higher K in the foliage than cooccurring western redcedar and, usually, lower Ca:Mg ratios (Imper and Zobel 1983).

Differences between Port-Orford-cedar and Pinaceae are more extensive. In general, Port-Orford-cedar foliage has lower concentrations of N, P, Mn, and B, but higher concentrations of Ca, Fe, Copper (Cu), and Zn than does Pinaceae in the Pacific Northwest (Ovington 1956, Youngberg 1958, Zobel and Hawk 1980, Zobel and Liu 1979) (see tables 16 and 17). Cedar often has a higher Ca:Mg ratio, but results vary somewhat with the situation.

**Effects on growth.**—No critical or deficient levels of nutrients have been determined for Port-Orford-cedar, although poor mineral nutrition is said to delay development of mature foliage of Cupressaceae (Rehder cited by Woycicki 1954). In one experiment (Plocher 1977), however, variation of growth within four populations across the range of soils was most closely associated with foliar concentration of K, which ranged from 0.80 to 1.15 percent. Regressions including only K accounted for 64 to 95 percent of the variation in height growth. Addition of most other nutrients to the regression was significant; the final equations accounted for 97-99 percent of the variation. In equations for three of four populations, Ca and N were most important besides K. Variation in growth among populations on a single soil was not closely related to foliar K; the nutrients best related to growth were: (1) sedimentary soil—N, K, Mg (77 percent of variation accounted for); (2) ultramafic soil—P, Mg, Ca (67 percent); and (3) dune soil—P, Mg, K, Ca (92 percent).

In poorly growing English plantations of Port-Orford-cedar, mulching increases height fivefold (Leyton 1955), and reduces chlorosis (Weatherell 1953). In one case (Leyton 1955), the mulched trees had 2.49 percent N and 0.25 percent P in the foliage, compared with 0.59 and 0.06 for the control. Growth probably reflected the improvement in nutrition, although better water relations were thought to be the primary cause.

In New Zealand, cedar grows better where it adjoins or is mixed with plantations of pine than in pure populations (Weston 1971, personal observations of Lewis F. Roth).

In the examples cited above, growth of Port-Orford-cedar increased with higher foliar N and K, and usually with higher P. Sometimes, however, concentration of Ca was higher in slower-growing trees, and Mg and S usually were higher (Imper 1981, Leyton 1955, Plocher 1977).



Increasing foliar iron concentration above 34 p/m increased growth and reduced chlorosis of the cultivars 'Columnaris' and 'Pottenii' (Besford and Deen 1977), despite the fact that some macronutrient concentrations declined. In 'Columnaris', Fe at 256 p/m (a concentration common in natural and forest nurseries; see tables 37 and 41) reduced growth. Levels of an iron-dependent enzyme (peroxidase) were much more sensitive indicators of foliar iron than were plant size or chlorosis.

Removal of nutrients by seedling crops (producing 5123 to 6031 kg/ha dry weight) was: N—29-75 kg/ha; P—7-13; K—38-47; and Ca—26-48 (Youngberg 1958).

Fertilization of Port-Orford-cedar stands has apparently not been attempted. Fertilizing *Chamaecyparis obtusa* plantations in Japan has proven to be economically feasible (for example, Haibara and others 1977).

### Shade Tolerance

Minore (1979) lists Port-Orford-cedar as having moderate shade tolerance. He classifies it among its usual competitors as more tolerant than incense-cedar, sugar pine, Douglas-fir, and western white pine, and less tolerant than Shasta red fir, Bre'er spruce, white fir, Sitka spruce, grand fir, western redcedar, and western hemlock (species are listed in order of increasing shade tolerance). Minore's conclusion represents a compromise among the varying opinions about shade tolerance of Port-Orford-cedar. Franklin and Dyrness (1973, p. 92-93) conclude that it "... is not capable of reproducing under closed forest conditions and is replaced by more tolerant associates ... ." But planted seedlings successfully grow up through gorse and bracken (Hermann and Newton 1968, Krygier 1958) and the British found that "... it stands shade well ..." and "... can be used for underplanting other conifers or for bringing in under hardwood scrub" (Macdonald and others 1957, p. 48). Baker (1945, p. 434), referring to a greenhouse experiment, comments that "... its ability to survive and to put on height growth in low light is phenomenal." Others indicate that its shade tolerance varies: "Moderately tolerant of shade throughout life, but especially tolerant of heavy shade in early stages" (Sudworth 1908, p. 175); and "Competitive ability" (defined to include shade tolerance) is said to be high on wet sites in California *Abies concolor* zone forests, but only intermediate on mesic sites in the *Abies magnifica* zone (Sawyer and Thornburgh 1977).

Our recent work (Hawk 1977, Zobel and Hawk 1980) suggests that Port-Orford-cedar is the most shade-tolerant conifer species throughout much of its range, and that it reproduces more successfully in old-growth forests than is indicated by Franklin and Dyrness (1973). The cedar probably has a somewhat higher relative tolerance than is indicated by Minore (1979).

Community analyses by Hawk (1977) show Port-Orford-cedar reproducing well in all communities he recognized and contributing 17-93 percent of conifer saplings and 26-62 percent of conifer seedlings (seedlings are <1 meter tall); cedar's proportion of the reproduction was lowest in the most open and most shaded communities (tables 43 and 44). Reproduction of western hemlock considerably exceeded Port-Orford-cedar in importance only in the swordfern community, which was the most shaded community. Even there, the cedar maintained 118 saplings and 313 seedlings per hectare. Where white fir grows with the cedar, the two have similar amounts of reproduction (table 43).

**Table 43—Percentage of saplings and seedlings of Port-Orford-cedar, western hemlock, and white fir in Hawk's (1977) eight major forest communities**

Community	Saplings				Seedlings			
	Total	Port-Orford-cedar	western hemlock	White fir	Total	Port-Orford-cedar	Western hemlock	White fir
	number/ha	percent	percent	percent	number/ha	percent	percent	percent
Swordfern	810	27	70	--	1214	26	67	--
Rhododendron	373	29	32	--	873	44	50	--
Beargrass	762	57	28	--	1019	53	27	--
Tanoak	1082	93	--	--	1033	62	--	--
Mixed pine	791	17	--	14	1076	30	--	0
White fir-hemlock	715	34	14	31	1280	31	20	24
White fir	2293	55	--	21	1820	37	--	36
Mixed fir	1165	40	--	39	1042	33	--	36

-- = species absent.

**Table 44—Light reaching live conifer saplings in six communities, expressed as a percent of light in the open**  
(In percent)

Community	Species				
	Port-Orford-cedar	Western hemlock	Douglas-fir	Pine spp.	White fir
Swordfern	0.7	0.6			
Tanoak	2.9		9.5	8.7	
Mixed pine	37.1		44.8	33.3	
Terrace	3.4		4.9		
White fir	2.1			1.2	3.6
Mixed fir	5.4				5.7

Source: Zobel and Hawk 1980.

Unpublished data from eleven 375-m<sup>2</sup> plots are cited by Franklin and Dyrness (1973) and also are presumably used by Daubenmire (1969) and Franklin and others (1972, sections CO and PO). The data show four plots where Port-Orford-cedar considerably exceeded western hemlock (averaging 36 cedar to 4 hemlock) in numbers of small trees (<10 cm d.b.h.), two plots where hemlock dominated (average 1 cedar to 97 hemlock), three where both were important (26 cedar to 21 hemlock), and two where neither was important (1 cedar to 4 hemlock). This seems to indicate neither consistent dominance of hemlock nor failure of Port-Orford-cedar. Port-Orford-cedar had more reproduction than grand fir in the five plots where they both grew (averaging 30 cedar to 13 fir).

Light was measured in the tops of understory saplings of six of Hawk's (1977) major communities and in one stream terrace stand (table 44). Incense-cedar, Jeffrey pine, and Douglas-fir received significantly more light than did Port-Orford-cedar on the same sites; other species were not statistically different from Port-Orford-cedar (Zobel and Hawk 1980). Port-Orford-cedar saplings were growing with less than 1 percent of full sunlight in the swordfern community. There is evidence, however, that Port-Orford-cedar cannot survive in the darkest microsites. Dead cedar saplings in two stands averaged 0.2 and 0.4 percent light compared to 0.7 and 2.5 percent, respectively, for living ones (Zobel and Hawk 1980). Young, dense cedar stands have little reproduction of any kind. One mixed stand with Sitka spruce, western hemlock, and Douglas-fir had 0.9 percent light reaching the forest floor and no tree reproduction. Planted seeds germinated and established better there than in more open sites, but no seedlings survived the second growing season (Zobel 1980). Similar measurements of other species in southwestern Oregon indicate lower limits for light for white fir are similar to, and for Douglas-fir similar to or usually above, those for Port-Orford-cedar (Atzet and Waring 1970, Emmingham and Waring 1973).

In coastal Coos County, cedar, western hemlock, and Sitka spruce all establish and grow up through dense red alder; cedar can do this in other areas also.

Our evidence from the field suggests that Port-Orford-cedar usually reproduces as or more effectively in the shade than any of its major associated conifers; the only exception is western hemlock in the most mesic old forests. Even there, Port-Orford-cedar grows at low light intensities and maintains a sizable population of reproduction and small trees (Hawk 1977).

The only experimental study of effects of shading on Port-Orford-cedar (Baker 1945) included several associates usually considered to be less shade tolerant: Douglas-fir, Jeffrey pine, incense-cedar, and redwood. After emphasizing the complexity of seedling responses to shade, Baker concluded that, "Ability to maintain life in the shade is measurable only by — ability to maintain life in the shade" (p. 433). Port-Orford-cedar reacted similarly to the pattern theoretically expected for a tolerant tree and had higher survival at the lowest light intensity than the other species. Its ratio of top height to dry weight in dense shade ("index of slenderness") was the highest of all species. Dry weight gain of 100-day-old seedlings increased seven-fold, top:root ratio decreased from 3.0 to 2.2, and height increased from 65 to 120 mm as light intensity for growth was increased from 10 percent to 70 percent of full light.

Baker (1945) also found that full light reduced survival of Port-Orford-cedar to about half that in the deepest shade, as well as somewhat reducing growth. In the field, however, the species will establish well in the open (Franklin and Dyrness 1973, Hayes 1958, Sudworth 1908, Zobel and Hawk 1980).

#### Responses to Damaging Agents

**Native diseases and insect pests.**—Port-Orford-cedar is singularly free of attack by native pathogens and insects. Those described (Furniss and Carolin 1977, Hep-ting 1971, Shaw 1973, U.S. Department of Agriculture 1960) appear to be well integrated into the biological communities and unlikely to threaten productivity of the forest; none is fatal or apparently debilitating.



In some years, pink larvae of the Port-Orford-cedar midge, *Janetiella siskiyou* Felt, greatly reduce the seed crop. The midge occurs both in the natural range (Felt 1917) and in Europe (Gagne 1972). The seeds contain a substance that acts as a juvenile hormone on some (nonendemic) insects (Jacobson and others 1975).

The major insect pests are cedar bark beetles (*Phloeosinus* spp.), which attack dying or dead trees in large numbers (Kliejunas and Adams 1980, Roth and others 1957, Wright and Mitchell 1954). They may kill some live trees where root rot mortality or large amounts of slash have allowed high beetle populations to develop, and where cedars at the edge of harvest units are stressed due to exposure. Although cedar bark beetles have little impact on forest productivity, their effects complicate diagnosis of root rot and require caution with some stand management decisions. Port-Orford-cedar is listed as a host of *P. sequoiae* Hopkins, which is more aggressive than most species of the genus (Furniss and Carolin 1977).

The amethyst cedar borer (*Semanotus amethystinus* [Le Conte]) and the cedar tree borer (*S. ligneus* [F.]) attack boles and large limbs of the species. The blazed tree borer (*Serropalpus substriatus* Haldeman) bores into dead trees (Furniss and Carolin 1977). Bark from Port-Orford-cedar stimulates feeding of the white pine weevil (*Pissodes strobi* Peck) less than does the bark of most conifers (Alfaro and Borden 1982). Other insects occur, apparently without major effects, on cultivated specimens (Carter and Young 1973, Wheeler and Henry 1977). Spider mites may become important on some cultivars; the mites feed on the underside of foliage during hot, dry weather (den Ouden and Boom 1965).

The only significant native pathogen is an unidentified fungus that causes a destructive, honeycombing, white pocket rot in the tops of old timber. This rot may extend downward through the bole, even to stump height, to involve several logs and result in extensive cull. The fungus produces no external indicators; consequently, estimating deductions from merchantable volume must rely on the judgment of experienced cruisers and data from adjacent or comparable stands.

**Introduced diseases.**—Damage to Port-Orford-cedar by introduced pathogens is extensive. Although these pests are not numerous, two soil-borne aquatic fungi, *Phytophthora cinnamomi* Rands and *Phytophthora lateralis* Tucker and Milbrath, cause fatal root rots. *Phytophthora cinnamomi* is distributed worldwide in favorable habitats on hundreds of species of trees and shrubs, including Port-Orford-cedar and most of our commercial conifers. The fungus requires some summer irrigation (Roth and Kuhlman 1966) and, consequently, is poorly suited to the forest habitat of the Pacific Northwest. It is a problem in nurseries and landscape plantings.

*Phytophthora cinnamomi* appears to have originated in southeast Asia (Shepherd 1975). It is a significant problem in Europe where horticultural Port-Orford-cedar continue to be produced in substantial numbers. Modern fungicides (furalaxyl and aluminum ethyl phosphate) for aquatic fungi (Phycomycetes) are effective in greenhouse studies (Bertus and Wood 1977, Smith 1980).

*Phytophthora lateralis* appears to be restricted to *Chamaecyparis* along the central west coast of North America and is ideally suited to both climate and soils (Trione 1959). *Phytophthora lateralis* is destructive in the native forest (Roth and others 1957), in horticultural nurseries, and to specimen and windbreak trees (Roth and others 1972, Torgeson and others 1954). Although no USDA Forest Service nursery is known to be contaminated,<sup>15</sup> the prolonged absence of cedar from these nurseries makes it difficult to monitor the condition. The fungus does occur in forest nurseries in British Columbia.<sup>16</sup>

Port-Orford-cedar cannot be managed to produce future rotations without dealing effectively with *Phytophthora lateralis* root rot. Correct management depends on a sound understanding of the disease; present knowledge of *P. lateralis* and the resultant root rot is summarized in Chapter 7 and recommendations for management are presented in Chapter 8.

**Animals.**—Animal damage to Port-Orford-cedar can be severe, but apparently is not usually a problem; no general conclusion about relative susceptibility seems justified from the limited data. James (1958, p. 2) reports that "Port-Orford-cedar is more heavily browsed by animals than are other common associates—thus verifying a common observation." He found 19 percent of the trees in plantations had at least moderate damage (mostly from deer and elk) as compared to 8 percent for Douglas-fir. In one plantation north of the range, 70 percent of cedar was damaged and only 20 percent of Douglas-fir (Ruth 1957). Another report (Schenck 1907, p. 93) says that mice eat the bark or roots and in general "game are very bad." Other authors report the opposite results: Cedar escaped or was less damaged, especially by rabbits, where Douglas-fir was destroyed or greatly deformed, both inside the normal range (in dense cover) (Hermann and Newton 1968, Lavender 1953) and outside the range (Staebler and others 1954). In a Washington plantation (Staebler and others 1954), 4-year height of deformed cedars was 14 percent less than for apparently undamaged trees (compared to 32 percent for Douglas-fir and 44 percent for western hemlock); however, intact cedars were still shorter than damaged Douglas-fir. More recently, in contrast to James' (1958) comment, forest managers have reported no important animal problems in naturally regenerated stands. Mountain beaver eat the foliage, wood rats and porcupines remove the bark, and elk and deer browse; however, there is no apparent preference for cedar and in some areas there is obviously less damage to cedar than to Douglas-fir. Some loss of small seedlings occurs, apparently to small mammals and birds (Moore 1940).

Although some small rodents apparently dislike the seeds of Port-Orford-cedar (Moore 1940), squirrels do harvest the cones and remove the seeds (Zobel 1979).

<sup>15</sup>Unpublished reports, 1958-1960, Northwest Forest Pest Action Council, Portland, Oregon.

<sup>16</sup>Unpublished report, 1954, J.P. Salisbury, on file at Canada Department of Agriculture, Forest Biology Laboratory, 409 Federal Building, Victoria, BC, Canada.

**Table 45—Freezing resistance (temperature low enough to kill) of twigs collected in winter from *Chamaecyparis* species and some conifers associated with Port-Orford-cedar that were grown in Japan**

Species	Seed source	Killing temperatures			Growth in Hokkaido
		"Bud" 1/	Leaf	Twig	
		- - - - - °C - - - - -			
Port-Orford-cedar	California	-15	-20 to -25	-25 to -30	Impossible
Alaska-cedar	USA	--	-20	-25	--
<u>Chamaecyparis obtusa</u>	Japan	-20	-20 to -35	-25 to -30	Bad
<u>Chamaecyparis pisifera</u>	Japan	-20	-20 to -30	-20 to -25	Bad
Western redcedar	Washington	-20 to -30	-30 to -40	-25 to -40	Impossible
Redwood	California	-15	-15 to -20	-15 to -20	Impossible
Douglas-fir	Washington	-20 to -25	-20	-20 to -25	Bad
Grand fir	British Columbia	-20	-50	-50	Bad
Sitka spruce	Washington	-20	-30	-30	Bad

-- = no data available.

1/ "Bud" = apical meristem.

Source: Sakai 1982, Sakai and Okada 1971.

**Extreme temperatures.**—The shoot apical meristems of hardened Port-Orford-cedar die at  $-15^{\circ}\text{C}$  in a laboratory test of cold hardiness (table 45); leaves and twigs are somewhat hardier. Conifer associates (from more northern sources) resist slightly lower temperatures, and Japanese *Chamaecyparis* have slightly more resistant apical meristems (table 45).

Killing of Port-Orford-cedar by frost has occurred in several areas. Low mortality and considerable top-kill occurred in plantations along the northern Oregon coast at 290 m; no damage occurred at lower elevations (Krygier 1958). Plantation trees in Washington were killed or severely damaged by severe cold in November 1955 when minimum temperatures were about  $-14^{\circ}\text{C}$ ; the blue variety 'Allumi' "showed resistance" (Duffield 1956). Sitka spruce was damaged less than the cedar. Port-Orford-cedar has been killed by cold in Europe in several instances (Day and Peace 1946, Forestry Commission 1965, Hayes 1958, Macdonald and others 1957, Welch 1966). Other reports stress its relative hardiness there; winter temperatures as low as  $-26^{\circ}\text{C}$  have not harmed Port-Orford-cedar in Britain (Dallimore and Jackson 1966). Much damage to the cedar is associated with dry, windy weather in combination with the cold (Duffield 1956, Forestry Commission 1965, Welch 1966).



In 1935, a May frost that moderately damaged Port-Orford-cedar and Douglas-fir severely damaged western redcedar, western hemlock, grand fir, and Sitka spruce in the same British plantation (Day and Peace 1946). Macdonald and others (1957, p. 48) state that "low temperatures in winter do not harm this tree," but there is more damage in spring. On the contrary, Sudworth (1908) considers it more resistant to late than to early frosts because it starts growth late. It is less frost hardy as a seedling (Sudworth 1908). The temperature necessary for damage, the most susceptible time of year, and the tolerance of Port-Orford-cedar relative to its associates all vary among reports.

There is little information about heat-tolerance of Port-Orford-cedar. Baker (1945) feels that reduced seedling survival in full light probably results from associated higher temperatures. The species grows and reproduces in open forests on serpentine, however, where maximum air temperatures (at 1 m) average 35 °C in the warmest month and exceed 40 °C several days each summer (Zobel and Hawk 1980).

**Wind and snow.**—Port-Orford-cedar is able to withstand strong wind and although it can be damaged by wind with wet snow, it is not overly susceptible (Holubcik 1960, Macdonald and others 1957, Radu 1960). Stands partially killed by root rot are windthrown more than are healthy ones. The species does grow naturally in areas having a persistent winter snowpack (see table 3).

**Fire.**—Large Port-Orford-cedar trees have thick bark and often bear fire scars. In some cases, fire has removed all except a thin, incomplete outer shell of wood and bark at the tree base (for example, fig. 63 in Franklin and Dyrness 1973), yet the trees remain healthy and standing for decades, probably centuries. Some smaller scars heal completely. Fire scars are usually not invaded by rot or insects.

Even as a pole-sized tree, Port-Orford-cedar has a good chance of surviving a ground fire. Its resistance is said to be less than that of Douglas-fir but greater than that of true firs and hemlock.<sup>17</sup> Silvicultural underburning of pole stands may be feasible with cedar. Smaller trees are readily killed by fire (Hayes 1958) and do not appear to be any more fire-tolerant than do associated species. Fire resistance is considered to be "medium" in California, less than that of ponderosa pine, Jeffrey pine, sugar pine, Douglas-fir, and incense-cedar (Sawyer and Thornburgh 1977).

Repeated fires have occurred in many old stands (Hawk 1977). For example, one stump (54 cm diameter, 285 years old) near the northern end of the species' range had fire scars at 35, 183, and 228 years. The fire frequency in the upper Illinois Valley was greater than that in the Oregon Coast Ranges (see footnote 17). A regime of repeated fires that killed part of the overstory probably increased the proportion of cedar in many stands because it could survive fire better than other shade-tolerant species and could establish under the residual overstory better than Douglas-fir (Hawk 1977). More frequent fires in other areas appear to favor Douglas-fir (Atzet 1979), which probably attains thick bark at a younger age but is

<sup>17</sup>Personal communication, 1981, T. Atzet, Area Ecologist, USDA Forest Service, Grants Pass, Oregon.

**Table 46—Tree density in 1980, by diameter size classes, in the Nickel Creek Burn, Coos County, OR, 28 years after the fire, on a relatively poor, high-elevation site on serpentine soil**

(In trees per hectare)

Species	Diameter class						
	0-2 cm	3-7 cm	8-12 cm	13-17 cm	18-27 cm	28-53	53+ cm
Port-Orford-cedar	1546	57	20	20	30	44	12
Western white pine	494	138	59	17	25	7	2
Douglas-fir	205	30	82	--	--	7	2
Western hemlock	198	10	--	--	7	2	--

-- = absent.

Source: Unpublished data on file, Powers Ranger District, Powers, OR.

less shade-tolerant than cedar. Following fire in coastal Oregon, Port-Orford-cedar is the first conifer to reinvade (Sargent 1884). It often dominated the volume remaining in recent burns (see footnotes 6 and 7) probably because dead trees retained their merchantability for many years. Data from one partially killed mixed stand on peridotite show that western white pine and Douglas-fir dominate the larger regeneration, although the smallest size class is predominantly cedar (table 46).

Part of the fire resistance of Port-Orford-cedar may be due to the undulating interface between wood and bark near the tree base, which causes the bark to vary in thickness. The very thick areas of bark almost surely allow partial survival by the cambium in fires that would completely kill the cambium of a tree with the same average bark thickness evenly distributed around its circumference.

After logging, dead Port-Orford-cedar twigs do not shed their needles and the fine slash does not collapse onto the forest floor as does that of Pinaceae. The litter dries quickly, has good aeration, and ignites explosively when dry.<sup>18</sup> Cedar litter in standing timber also appears to burn faster than other litter types.

**Air pollution.**—Port-Orford-cedar can withstand moderate air pollution but grows poorly where pollution is heavy (Macdonald and others 1957). The sensitivity of Port-Orford-cedar to sulfur dioxide has been tested (Enderlein and Vogl 1966). Exposure for 57 hr at 1.9 p/m resulted in only slight visible injury. Such treatment drastically reduced photosynthesis on the second and third days of exposure, however; it had less effect on Douglas-fir and none on western redcedar. Port-Orford-cedar is said to be sensitive to damage by nitrogen dioxide but *Chamaecyparis* spp. are listed as relatively insensitive to NO<sub>3</sub> (Bernatzky 1978).

<sup>18</sup>Personal communication, 1981, personnel of USDA Forest Service, Powers Ranger District, Powers, Oregon.

## Vegetative Phenology

Twig elongation of Port-Orford-cedar, as for all Cupressaceae, follows a cycle different from that of Pinaceae. Although the apex is cutinized, there are no bud scales. There is no late-season formation, inside the protection of a bud, of leaves and internodes that can then rapidly expand the following year. In Berkeley, CA, south of the native range, slow growth continues all year, and there is no complete winter dormancy (Al-Sherifi 1952, Ersamer 1953). "However, the apical meristem appears to experience a kind of cessation in its growth, which is characterized by very infrequent mitotic divisions, small size of the apex and virtual cessation of leaf initiation" in the winter. "From the middle of March to September, one may observe numerous mitotic figures, active leaf formation, and the large size of the apical meristem" (Al-Sherifi 1952, p. 19).

Shoot expansion occupies much of the growing season. A comparison of leading shoots of many young conifers in Great Britain (Mitchell 1965) shows that Port-Orford-cedar start growth slowly and "hesitantly," but then grow steadily for a long period, the growing season lasting from May 8 to September 5. Port-Orford-cedar starts growing within a week of most associated conifers; the exceptions are lodgepole pine (3½ weeks earlier) and incense-cedar (3½ weeks later). Growth for Port-Orford-cedar ends later than for all species with which it naturally grows. Lengths of growing season (days) in Great Britain were: western redcedar, 123; Port-Orford-cedar, 120 (range 75-147 days); western hemlock, 102; Sitka spruce, 87; lodgepole pine, 69; grand fir, 63; Douglas-fir, 56; and white fir, 41.

Lateral twig elongation of native saplings is highly variable (Zobel 1983). At sites with more moderate, maritime climates, growth lasted the longest; at hot sites it usually started at a similar time but ended earlier than near the coast; and at cold sites it both started and ended later (table 47). The time for elongation from 5 to 95 percent of final length ranged from about 80 days at the hottest site to over 150 days in the open in coastal Coos County, and occupied from 35 to 89 percent (mean, 62) of the frostless season in 1975. At the Coos County Forest, significant elongation continued into October. At sites with a similar mean temperature, growth was earlier in California than in Oregon (fig. 17).

The acceleration of growth of native Port-Orford-cedar saplings in the spring was closely related to air temperature (Zobel 1983). Lateral twigs of cedars in the *Tsuga heterophylla* zone grew at average day temperatures of about 4.5 °C; those in other zones grew only above 6 °C. Growth of trees in the cold *Abies concolor* zone increased faster with rising temperature than did growth in other zones. Elongation of the leaders was less clearly related to environment than was elongation of the lateral branches. Lateral twig elongation of Douglas-fir, western hemlock, and white fir lasted a shorter time than did that of cedar on the same sites: hemlock usually started later; Douglas-fir was earlier on some sites and later on others; and white fir started about the same time as the cedar.

There is no evidence of significant twig elongation by native Port-Orford-cedar during late fall and winter (Imper 1981, also see footnote 10).



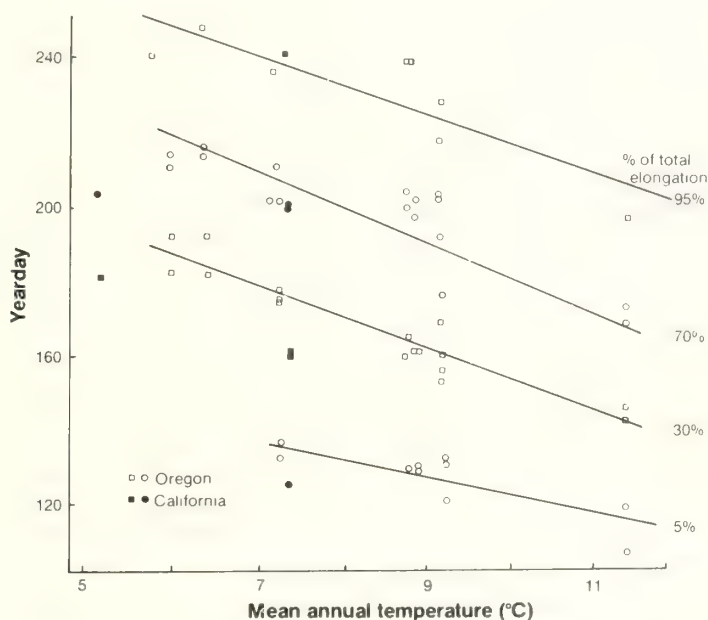
**Table 47—Mean dates for native seedlings of Port-Orford-cedar in each vegetation zone to complete 5, 30, 70, and 95 percent of lateral twig elongation, with periods required for 30-70 percent and 5-95 percent elongation**

Vegetation zone	Number of populations	Date reached						Days required			
		5 percent		30 percent		70 percent		95 percent	30-70 percent		5-95 percent
		1975	1976	1975	1976	1975	1976	1975	1975	1976	1975
<i>Tsuga heterophylla</i>	2	May 5	May 9	June 9a 1/	June 13a	July 22a	July 22	Aug. 29	43a	40a	116
Mixed evergreen	6	May 4	May 5	June 7a	June 14a	July 8a	July 19	Aug. 13	31b	35ab	97
<i>Abies concolor</i>	3	--	--	July 13b	July 1b	Aug. 5b	July 29	Sept. 2	23b	28b	--

-- = no data available.

1/ Means in the same column with dissimilar letters are statistically different (0.05 level).

Source: Unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.



**Figure 17.—Day of the year when twig elongation reached 5, 30, 70, and 95 percent of final length at nine sites varying in mean annual temperature (January 1 is year-day 1). Regression lines are calculated for Oregon stands only. Each symbol represents the mean of several trees at one site. (Unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.)**

Timing of twig elongation was determined for populations of rooted cuttings grown together in a common plant bed; timing varied much less than that of populations in the field (Zobel 1983). Differences among populations were not significant. Elongation varied drastically in the 2 years sampled; elongation from 5 to 95 percent of total growth lasted 102-117 days in the first year and 160-175 days in the second. Differences among field populations apparently represent primarily the effects of local environment.

Twig elongation of seedlings transplanted into the greenhouse in March was still continuing 34 weeks later (Plocher 1977), but rooted cuttings kept in the greenhouse several years may elongate little, if at all, until placed outside.

The late, long-lasting twig elongation of Port-Orford-cedar may have important ecological consequences for the cedar (Zobel 1983). Slow, late growth may increase cedar's susceptibility to drought because new foliage is exposed all summer, and successful apical function and cell enlargement require high water potentials through much or all of the summer. Species that continue to grow into late summer can increase the current year's growth in response to late season management to improve the environment (Mitchell 1965).

## Growth and Size

**Height and branch length.**—New seedlings grow very little under a natural canopy. Height above the cotyledons averaged 3 mm, 14 mm, and 27 mm (maximum 52) after one, two, and three seasons, respectively, (Zobel 1980). Growth in the open is faster, with total heights of 36 and 79 mm for the first and second year, respectively, in the Port-Orford-cedar Experimental Forest (Hayes 1985).

Seedlings may grow much more in greenhouse or nursery conditions. Greenhouse-grown seedlings reached 25 to 100 mm (maximum 350 mm) above the cotyledons (which were 9 to 22 mm above the soil) in the first year (Franklin 1961). Height of 100-day-old seedlings in nutrient solution was 65 mm at 10 percent of full light and 120 mm at full light (Baker 1945). Nursery seedlings 14.5 months old averaged  $137 \pm 56$  mm tall (range 50-300 mm) in Taiwan (Liu and others 1975).

Height growth of natural saplings in the understory was estimated by aging young trees and by measuring sapling height increment for 2 or 3 years. The change in height with age varied considerably among communities both under a canopy and in clearcuts (figs. 18 and 19; table 48). Growth in the swordfern community was fastest, followed by that in open forest on Blacklock soil. Growth in clearcuts during the sapling stage was two to three times as fast as in the forest. Other species sampled at the same sites grew similarly or slower: Douglas-fir and western hemlock averaged 5 and 4 years to breast height, respectively, in clearcuts in the swordfern community; western hemlock averaged 16 years in swordfern community forests; white fir averaged 29 years in the three *Abies concolor* zone communities; and in the mixed pine community, Jeffrey pine averaged 33 years and Douglas-fir 31 years to reach breast height.

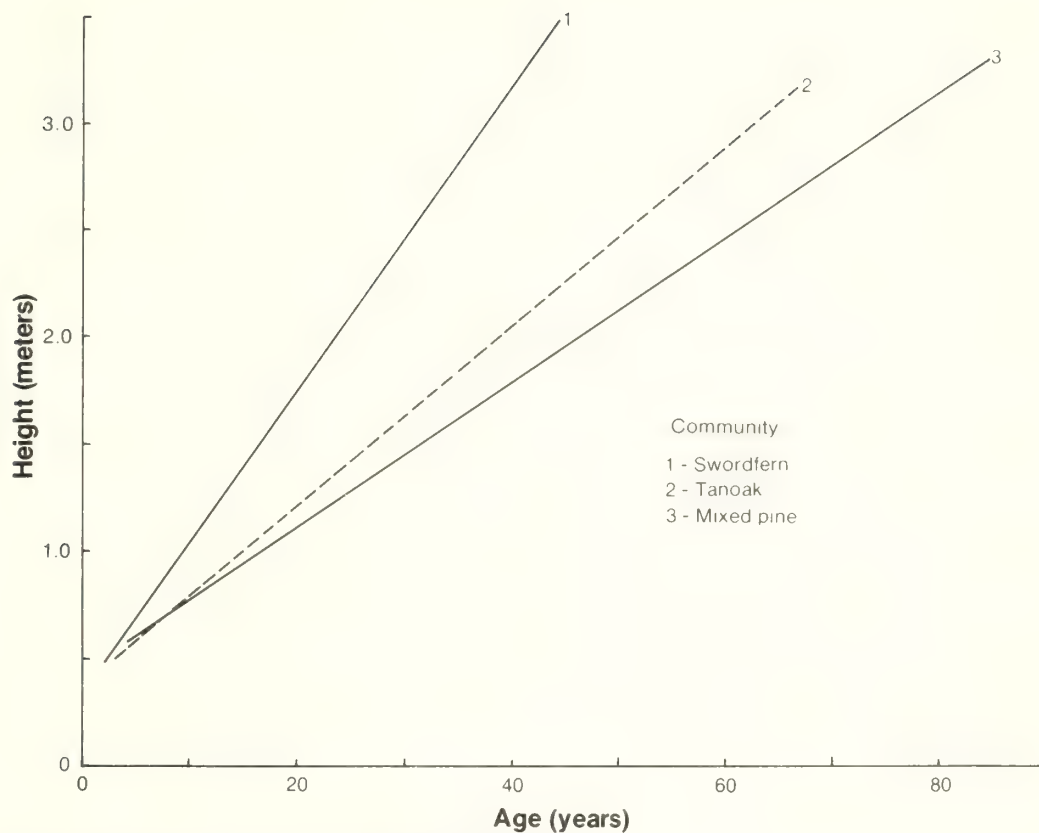


Figure 18.—Height-age relationships of Port-Orford-cedar saplings in three low-elevation forest communities. Regression equations for the communities ( $y$ =height [meters],  $x$ =age [years]) are: swordfern ( $n=35$ ,  $r^2=0.67$ ):  $y=36 + 7.0x$ ; tanoak ( $n=33$ ,  $r^2=0.80$ ):  $y= 43 + 3.4x$ ; mixed pine ( $n=44$ ,  $r^2=0.52$ ):  $y = 38 + 4.2x$ . (Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.)



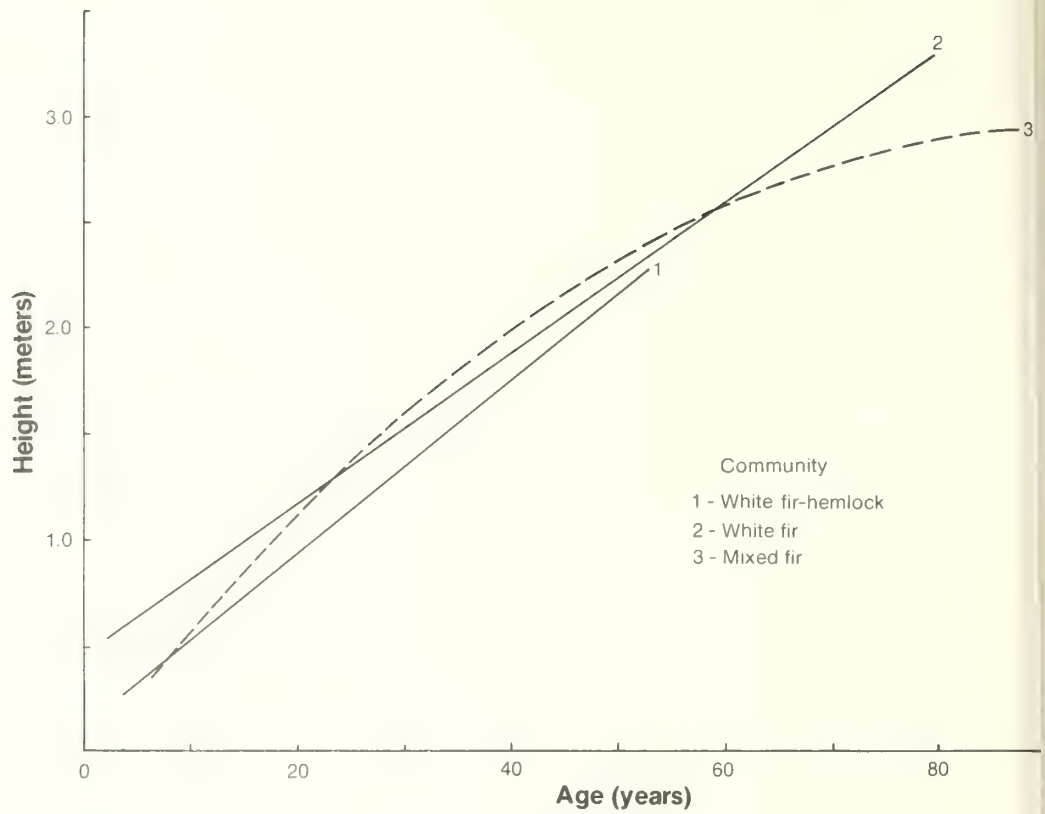


Figure 19.—Height-age relationship of Port-Orford-cedar saplings in three communities of the *Abies concolor* zone. Regression equations for the communities are: white fir-hemlock ( $n=43$ ,  $r^2=0.77$ ):  $y = 12 + 4.1x$ ; white fir ( $n=82$ ,  $r^2=0.76$ ):  $y = 46 + 3.6x$ ; mixed fir ( $n=49$ ,  $r^2=0.69$ ):  $y = -2.5 + 6.4x - 0.035x^2$ . (Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.)

**Table 48—Time necessary for natural Port-Orford-cedar saplings to reach breast height (137 cm) as measured from ring counts and as estimated from a regression of total height on age<sup>1/</sup>**  
(In years)

Community <sup>2/</sup>	Natural forest		Clearcut	
	Measured	Estimated	Measured	Estimated
Swordfern	12	14	4	5
Coastal terrace (Blacklock soil)	19	18	--	--
Tanoak	30	28	--	--
Mixed pine	28	24	--	--
White fir-western hemlock	27	31	--	--
White fir	27	26	--	--
Mixed fir	24	26	11	11

-- = no data available.

<sup>1/</sup> Sample sizes are 9-27 per community (measured) and 26-82 (estimated from regressions), except for 11-21 in clearcuttings.

<sup>2/</sup> As defined in Chapter 4.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

Elongation of terminal shoots of natural understory saplings varied considerably among sites within zones and among years (table 49). Terminal elongation was much greater in the open at Coos County Forest, 432 mm in 1976, than in the understory (table 49). Because of the cedar's growth form, however (see Chapter 5), some of the terminal elongation (as measured here) may not contribute to height growth.

Terminal elongation of small trees in a British plantation averaged 290 mm per year (range 150 to 690); maximum weekly increment was 50 mm. Growth was greatest in wetter years (Mitchell 1965).

Seedling height growth in a common environment varies considerably with the seed source and growing conditions. Height growth of native seedlings transplanted to the greenhouse varied with the soil type from which the seedlings were collected and the soil type in which they were grown (table 50). The coastal dune seedlings continued rapid elongation longer than the others (Plocher 1977). Height growth of rooted cuttings measured during their first and third years after outplanting in a plantbed in Corvallis, OR, varied twofold to threefold with source (table 51).

**Table 49—Elongation of terminal shoots of native understory Port-Orford-cedar saplings, by vegetation zone and year**

Zone	Number of sites	Elongation <u>1/</u>	
		1975	1976
<hr/>			
- - - - - <u>Millimeters</u> - - - - -			
<u>Tsuga heterophylla</u>	1	28	28
<u>Mixed evergreen</u>	4 to 6	30 (19 to 39)	38 (24 to 62)
<u>Abies concolor</u>	1 to 2	13	43 (39 to 47)

<sup>1/</sup> Range of site means in parentheses.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

**Table 50—Height increase of native seedlings from Coos County, OR, after transplanting into four field-collected soils in the greenhouse for 34 weeks <sup>1/</sup>**

(In millimeters)

Source of population	Soil			
	Sedimentary	Ultramafic	Dune	Blacklock
Inland sedimentary rock	199	105	41	21
Inland ultramafic	169	87	16	--
Coastal wet dune	234	153	43	--
Coastal Blacklock soil	174	107	31	25

-- = no data available.

<sup>1/</sup> Variation is significant among populations, among soils, and with their interaction.

Source: Plocher 1977.



**Table 51—Leader elongation of rooted Port-Orford-cedar cuttings grown in a plantbed in Corvallis, OR, first and third years after outplanting**

Source of cuttings (location)	Elevation	Leader elongation	
		1976 <u>1/</u>	1978 <u>2/</u>
	<u>Meters</u>	<u>---Millimeters---</u>	
Coastal and montane Coos Co., OR	10-520	178	232
Blacklock soil, Coos Co., OR	140	176	154
Montane serpentine, Coos Co., OR	850	101	202
Josephine Co., OR	1300	58	119
Sacramento River, CA	580	110	187

1/ The two longest differ significantly from the shortest.

2/ The longest differs significantly from the shortest.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis; Zobel 1983.

Seedling height growth is stimulated by a long (16 hr) photoperiod and even more by addition of gibberellic acid; hormone-treated trees were 160 mm tall at 14 weeks. Growth continued at a 10-hr photoperiod and was not significantly increased by interruption of dark hours; both this and the response to the hormone were opposite the behavior of Sitka spruce (Bonnet-Masimbert 1971).

Height growth of Douglas-fir past the sapling stage exceeds that of cedar off serpentine soil; cedar is overtopped in most mixed stands at 20-25 years (Hayes 1958). In 8- to 26-year-old plantations (Hayes 1958, James 1958), annual height growth of unbrowsed Port-Orford-cedar averaged 0.35 m, only 68 percent of that of Douglas-fir; when browsed trees were considered, the difference was much greater. Height growth in plantations in coastal Oregon, but north of the range, varied from very poor, 0.76 m in 10 years (about half that of Sitka spruce) (Ruth 1957), to the best of any plantations known, 9.5 m in 19 years (taller than Sitka spruce and about the equivalent to native western hemlock) (Krygier 1958).

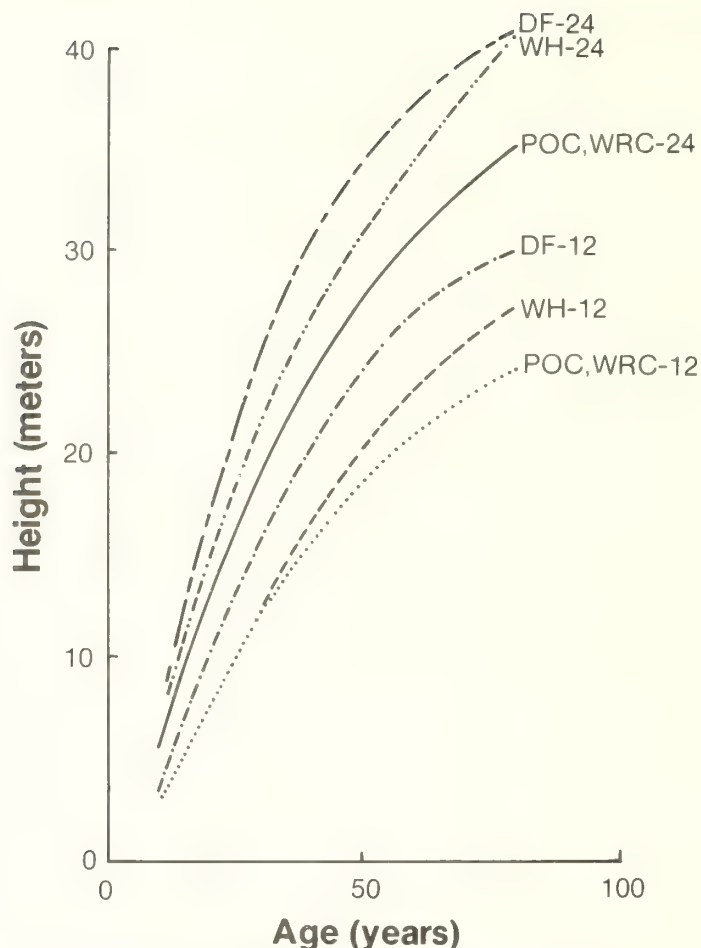


Figure 20.—Height of plantations of Port-Orford-cedar (POC), western redcedar (WRC), western hemlock (WH), and Douglas-fir (DF) for yield classes that produce 12 and 24 m<sup>3</sup>/ha in British plantations (Hamilton and Christie 1971).

In pole stands in the northern part of the range, large differences in tree size occur among species; for 53- to 60-year-old trees at one site in coastal Coos County, Douglas-fir was 38 m tall, cedar 28 m (see footnote 10). Height of other young natural stands measured in the northern end of the range was 16 to 22 m at 36 to 44 years and 22 to 23 m at 57 to 61 years (Hayes 1958). Trees in British plantations grow similarly to western redcedar (Hamilton and Christie 1971), but the cedar are considerably shorter than western hemlock or Douglas-fir of the same age (fig. 20). At Bedgebury, England, 29- to 31-year-old stands averaged 8.9 m tall for Port-Orford-cedar compared to 13.5 m for Douglas-fir, 12.8 m for western hemlock, 11.3 m for grand fir, and 7.5 m for western redcedar (Ovington 1953). Ten-year-old Port-Orford-cedar trees growing in Denmark are likewise shorter than are other Oregon conifers on the same 13 sites: mean height for Sitka spruce was 4.4 m; lodgepole pine, 3.9 m; Douglas-fir, 3.8 m; grand fir, 3.0 m; and Port-Orford-cedar, 2.3 m (range 0.8 to 5.0) (Holmsgaard and Bang 1977). Although young trees may grow as much as a meter per year in France, few exceed 35 m at 100 years (Boullard 1974). Height in New Zealand is similar to that in British and European plantations (Streets 1962).

The relationship of height of large, native Port-Orford-cedar trees to age varies with the plant community (figs. 21 and 22; table 52). Trees in the open mixed-pine type on ultramafic soil are relatively tall when young but then height increases slowly after 100 years. The tallest tree measured in Hawk's (1977) vegetation sampling was 69 m (80 cm d.b.h.) in the Coquille Falls Research Natural Area, Coos County. The tallest known cedar, south of Powers, OR, is 73 m.

Elongation of lateral twigs of native understory saplings varies among sites within the same zone and among years; year-to-year patterns can be quite different within the same zone (Zobel 1983) (table 53). During the 1976-1977 drought, growth increased on some shadier sites, but decreased in the open mixed pine forests. Elongation of branches of Port-Orford-cedar in the open at Coos County Forest exceeded growth in the forest, with 159 and 154 mm in 1976 and 1977 (compared to 272 and 250 for nearby Douglas-fir).

**Diameter.**—Basal diameter of 14-month-old trees in a nursery was 0.30 cm (Liu and others 1975). Growth in diameter of native saplings is greatest in open stands on poor (ultramafic and Blacklock) soils where saplings average a 1.4- to 1.6-mm increase per year at the base of a tree (see footnote 10). Saplings growing in closed forests average 1.0 to 1.2 mm per year. Basal diameter increase in clearcuttings is much faster: 4.6 mm per year on swordfern community sites and 2.9 mm in the mixed fir community. Diameter increments of associated conifer saplings are not significantly different from Port-Orford-cedar within a given community.

An average ring width of  $\geq 3.2$  mm is considered fast diameter growth for second-growth trees in Coos County; 1.6 to 3.2 mm per year is moderate (Stillinger 1953).

Young, natural stands in coastal Coos and Curry Counties are 16 to 24 cm d.b.h. at 36 to 44 years, and 28 to 31 cm d.b.h. at 57 to 61 years (Hayes 1958). In one mixed stand where 53- to 60-year-old cedar averaged 47 cm d.b.h., Douglas-fir averaged 73 cm d.b.h. Four coastal plantations 16 and 19 years old, north of the range, averaged 10 to 18 cm d.b.h. (Krygier 1958).

Diameters in thinned plantations in Britain averaged 10 to 14 cm (for the 12- and 24-m<sup>3</sup>/ha yield classes, respectively) at age 20, increasing to 32 to 53 cm at age 80. Plantings 29 to 31 years old at Bedgebury averaged 37 cm d.b.h. for Port-Orford-cedar, compared to 52 cm for grand fir, 51 cm for Douglas-fir, 47 cm for western hemlock, and 27 cm for western redcedar (Ovington 1953).

On productive soils in Coos County, unmanaged young Port-Orford-cedar increases in size much less consistently as it ages than does western redcedar (table 54). Although Port-Orford-cedar appears to grow more rapidly early, the basal area increment of western redcedar becomes larger at about 25 years (Imper 1981). Basal area increment of Port-Orford-cedar varied considerably with site; there was a significant increase with higher soil nitrate concentration (coefficient of determination  $r^2 = 0.30$ ). Basal area increment was closely related to tree diameter ( $r^2 = 0.74$ ).

Basal area of Port-Orford-cedar in Hawk's plots ranged from 19 m<sup>2</sup>/ha in the mixed pine community to 102 m<sup>2</sup>/ha in the beargrass community for stands over 200 years old (see table 19). Because these plots were chosen in well-developed forests, they probably exceed averages over large areas.



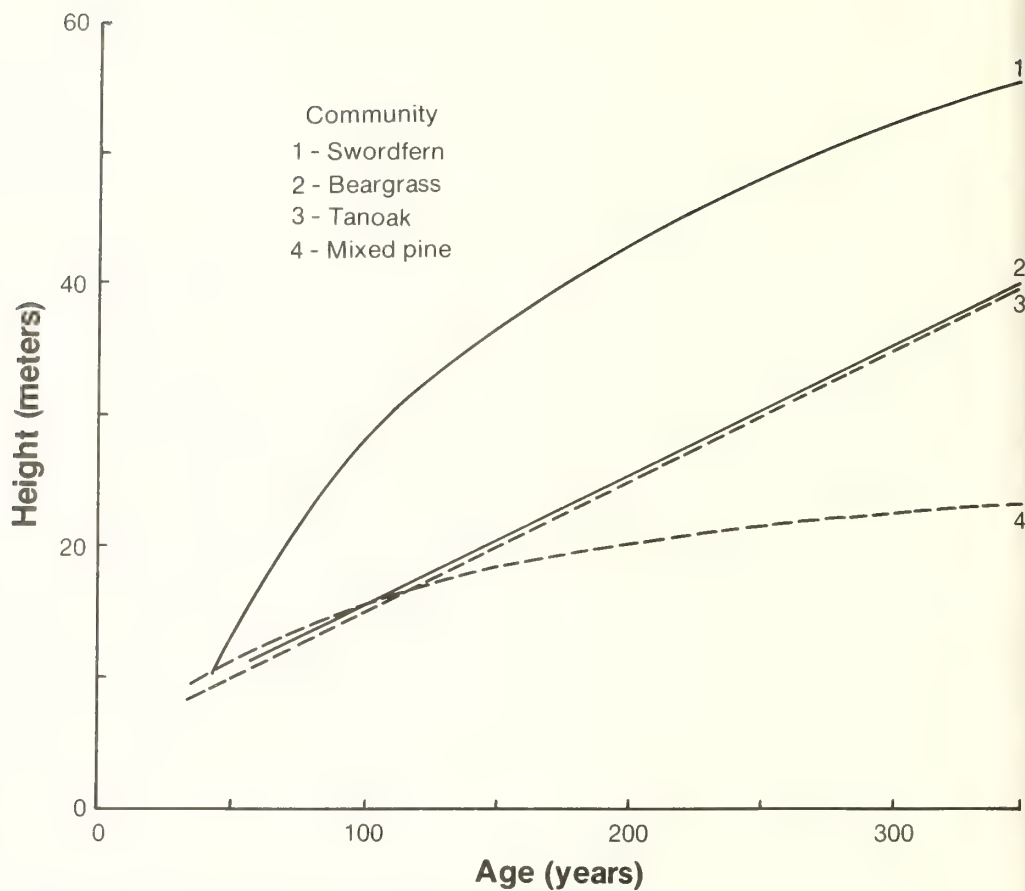


Figure 21.—Height-age relationship of Port-Orford-cedar trees in four low-elevation forest communities. Regression equations for the lines for each community ( $y$  = height [meters],  $x$  = age [years]) are: swordfern ( $n=68$ ,  $r^2=0.48$ ):  $y = -73.8 + 22.1 \ln x$ ; beargrass ( $n=164$ ,  $r^2=0.71$ ):  $y = 6.0 + 0.10x$ ; tanoak ( $n=83$ ,  $r^2=0.53$ ):  $y = 5.1 + 0.10x$ ; and mixed pine ( $n=86$ ,  $r^2=0.46$ ):  $y = -12.9 + 6.2 \ln x$ .

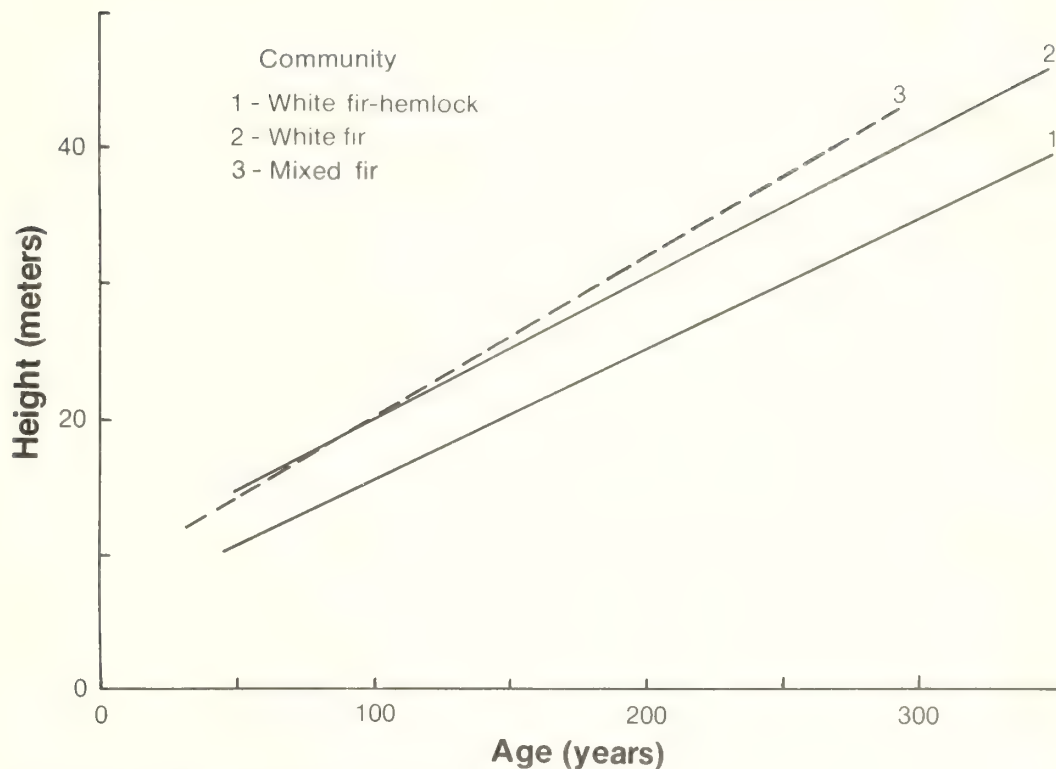


Figure 22.—Height-age relationship for Port-Orford-cedar trees in three communities in the *Abies concolor* zone. Linear regression equations for each community are: white fir-hemlock ( $n=136$ ,  $r^2=0.45$ ):  $y = 5.7 + 0.10x$ ; white fir ( $n=98$ ,  $r^2=0.36$ ):  $y = 9.7 + 0.10x$ ; mixed fir ( $n=71$ ,  $r^2=0.48$ ):  $y = 8.4 + 0.12x$ .

Table 52—Height of Port-Orford-cedar trees, 1, 2, and 3 centuries old ( $\pm 10$  years), major old-growth forest communities (In meters)

Community	Age (years)		
	100 $\pm$ 10	200 $\pm$ 10	300 $\pm$ 10
Swordfern	30	47	63
Rhododendron	--	45	53
Beargrass	13	25	31
Tanoak	12	29	44
Mixed pine	18	21	29
White fir-hemlock	12	26	41
White fir	13	25	46
Mixed fir	12	36	50

-- = insufficient data available.

Source: Hawk 1977.

**Table 53—Elongation of lateral twigs of native saplings, by community and site, for 3 years**

Community	Site <u>1</u> /	Years			Difference 1976-1977
		1975	1976	1977	
<hr/>					
		<u>Millimeters</u>			
		- - -		- - -	
Swordfern	Remote	52	54	40	NS
	Coquille				
	River Falls	32	43	53	*
Tanoak	Agness	23	37	32	NS
	Pine Point	28	41	41	NS
	Orleans	37	48	42	NS
Mixed pine	Agness	--	32	16	**
	Pine Point	38	72	51	**
	Kerby	29	29	26	*
White fir	Game Lake	19	49	56	*
	Castle Lake	--	26	28	NS
Mixed fir	Grayback	37	52	64	*

\*\* = significantly different at 0.01; \* = significant at 0.05 level;  
NS = not significant; -- = no data.

1/ Site locations shown in figure 5.

Sources: Unpublished data on file at Department of Botany and  
Plant Pathology, Oregon State University, Corvallis; Zobel 1983.



**Table 54—Correlation of height, diameter, and 10-year basal area increment with age, Port-Orford-cedar and western redcedar, and the predicted values for an age of 50 years, for unmanaged stands on productive soils in Coos County, OR <sup>1/</sup>**

Item	Port-Orford-cedar	Western redcedar
- - - <u>Correlation coefficient</u> - - -		
Correlation of age with:		
Height	0.38	0.66
D.b.h.	.36	.76
Basal area increment	.27	.60
Predicted value, 50 years:		
Height (meters)	15.4	14.9
D.b.h. (centimeters)	18	19
10-year basal area increment (square centimeters) at 50 years	36	65

Source: Imper 1981.

Throughout much of their life, cedars grow more slowly in diameter than Douglas-fir; however, in trees older than about 300 years, growth rate of cedar declines less than does that of Douglas-fir (fig. 23). The ratio for wood basal area of Douglas-fir to Port-Orford-cedar declines from 3.1 at 100 years to 1.2 at 400 years.

Diameter reached by old trees and the relationship to height vary considerably among forest communities. Old-growth trees on ultramafic materials do not grow as large (table 55) and are shorter for their diameter (for example, fig. 24) than are those on most other soils.

Port-Orford-cedar occasionally reaches 1 m d.b.h.; Hawk (1977) encountered 28 such trees from 220 to over 560 years old. Of these, 7 were less than 300 years old, 12 were 300 to 350 years old, 5 were 350 to 400 years old, and 4 were over 400 years.

The largest known Port-Orford-cedar, south of Powers, OR, was 67 m tall, 1146 cm in circumference (equivalent to a diameter of 3.65 m), and had a crown spread of 12 m in 1972 (American Forestry Association 1978). In 1981 a sign at the tree gave height as 73 m, diameter as 3.78 m, and volume as 255 m<sup>3</sup>.

**Volume and yield.**—Estimates of volume growth are few. Port-Orford-cedar in young stands in coastal Oregon (see table 32) produce a mean annual increment of 5.1 to 11.5 m<sup>3</sup>/ha at 36 to 44 years and 13.7 to 16.9 m<sup>3</sup>/ha in older stands. Production in young European plantations and better ones in New Zealand is somewhat similar (tables 56 and 57).

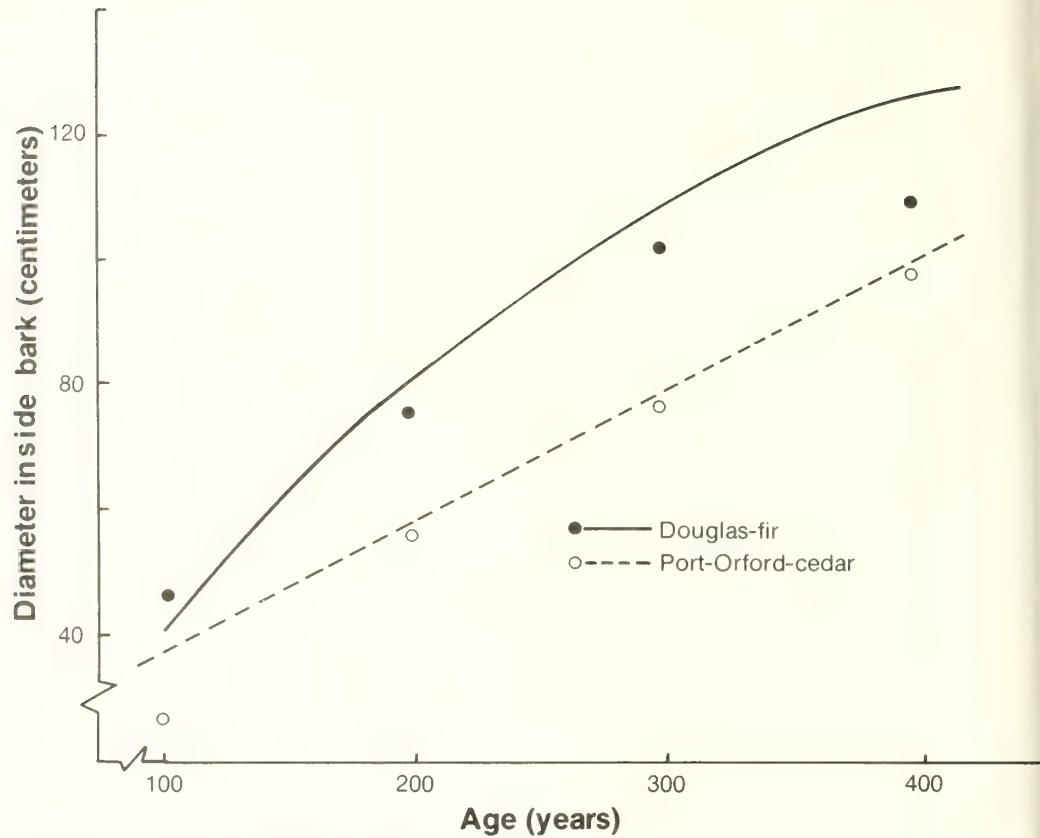


Figure 23.—Change of diameter inside bark with age for native Port-Orford-cedar and Douglas-fir. Regression lines are constructed from diameters and ages of 67 and 23 stumps, respectively, from the same group of sites throughout the range;  $R^2$  values for the regressions are 0.65 and 0.47, respectively. Plotted points are average inside-bark stump diameters at 100, 200, 300, and 400 years for all stumps reaching a given age; numbers decline from 56 Port-Orford-cedar and 23 Douglas-fir at 100 years to 4 and 7 trees, respectively, at 400 years. (Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.)

Table 55—Diameter of a tree of mean basal area in forests 200 years or older for eight major forest communities

(In centimeters)

Forest community	Community							
	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed fir
Port-Orford-cedar	86	66	51	63	43	51	45	68
Douglas-fir	95	137	65	96	48	84	50	58
Western hemlock	26	32	33	—	—	36	—	—
Pines	--	--	38	71	21	--	76	62
White and Shasta red fir	--	--	--	--	--	26	99	54
Other conifers	46	54	--	--	38	38	30	45
Hardwoods	29	--	51	35	--	22	--	18
Primary substrate is ultramafic	-	-	+	+	+	-	+	-

-- = absent; - = no; + = yes.

Source: Hawk 1977.

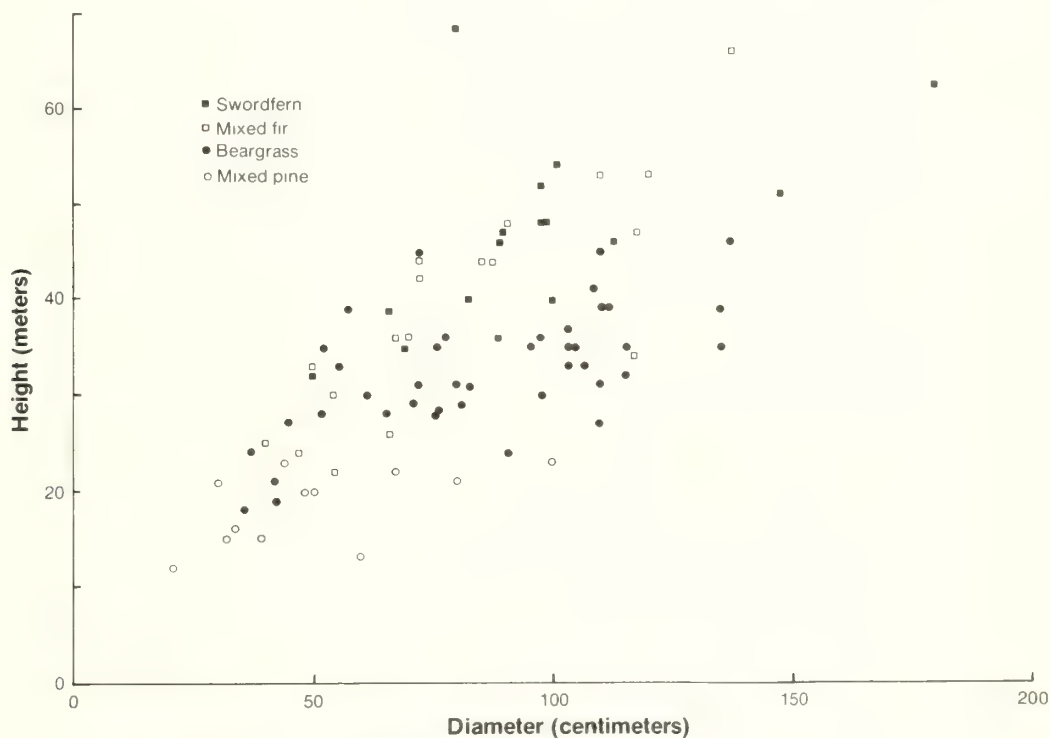


Figure 24.—Relationship of height and diameter of trees over 200 years old in four forest communities. Beargrass and mixed pine communities grow on ultramafic substrates. (Unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.)



**Table 56—Yield per hectare of Port-Orford-cedar in young plantations, Europe and New Zealand**

Location	Stand age	Stems	Basal area	Average diameter	Average height	Volume	Mean annual increment
	Years	Number	Square meters	Centimeters	Meters	--- Cubic meters ---	
Belle-Etoile, Belgium	20	2978	28	11	8	98	4.9
Belle-Etoile, Belgium	30	2637	46	15	13	275	9.2
Westland, New Zealand	28	988	--	22	13	223	7.9
Holstenshuus Forest District, Denmark:							
Living trees	28	2126	34	14	13	273	12.8
Removed in thinning	--	1657	14	--	--	84	
Living trees	46	1301	50	22	17	471	13.4
Removed in thinning	--	1284	20	--	--	144	
Vernand-Dessons, Switzerland 1/	45	840	--	24	22	527	11.7

-- = no data.

1/ Planted in mixture with beech and spruce. Some cutting mentioned. Included only about half the number of cedar stems desired for pure stands on good sites.

Sources: Hayes 1958, Streets 1962.

**Table 57—Yield per hectare of Port-Orford-cedar in young plantations, New Zealand**

Location 1/	Stand age	Basal area	Average height	Volume	Mean annual increment
	Years	Square meters	Meters	--- Cubic meters ---	
Flagstaff	38	83.1	13.4	484.8	12.8
Hamner	45	53.0	20.4	447.5	9.9
Port Chalmers	45	106.1	17.7	678.0	15.1
Ross Creek	47	108.1	23.5	927.7	19.7
Mahinapua	47	88.1	22.1	756.5	16.1
Golden Downs	48	40.1	20.2	280.1	5.8
Golden Downs	48	36.9	20.4	270.5	5.6
Karioi	51	29.3	22.3	237.0	4.7
Karioi	51	69.3	21.6	532.5	10.4
Karioi	51	8.2	12.8	11.6	.2
Karioi	51	13.3	18.7	86.7	1.7
Karioi	51	18.7	16.6	89.6	1.8
West Tapanui	66	60.3	23.7	512.5	7.8
Raincliff	78	82.2	35.1	1003.8	12.9

1/ All except Karioi are on the South Island.

Source: Personal communication, 1982, B.P. Glass, New Zealand Forest Service, Rotorua.

**Table 58—Attributes of British plantations of Port-Orford-cedar and western redcedar for the least and most productive yield classes (supporting maximum mean annual increment of 12 and 24 m<sup>3</sup>/ha)<sup>1/</sup>**

Age	Density		Height		Diameter		Basal area maintained after thinning		Cumulative yield	
	12	24	12	24	12	24	12	24	12	24
years	trees/ha <sup>2/</sup>		meters		centimeters		- - m <sup>2</sup> /ha - -		- - m <sup>3</sup> /ha - -	
20	3575	2186	8	13	10	14	28	35	50	232
40	1730	746	16	24	18	30	42	54	377	901
60	984	451	21	30	26	43	51	66	706	1439
80	738	347	24	35	32	53	59	76	953	1838

<sup>1/</sup> Yields include thinnings and are computed for top diameter of 7 cm outside bark.

<sup>2/</sup> 1 tree/ha = 0.405 tree/acre.

Source: Hamilton and Christie 1971.

Estimated yields in British plantations for Port-Orford-cedar and western redcedar (considered as a unit) range from 12 to 24 m<sup>3</sup>/ha at the peak of mean annual increment (Hamilton and Christie 1971) (table 58); this is within and higher than the ranges for young stands cited above. The peak value of mean annual increment was first reached at 55 to 70 years. The pattern of current annual increment differed from Douglas-fir and western hemlock and with the productivity of the site (fig. 25). Growth of Douglas-fir, as noted above for the natural range, is earlier. Compared to Douglas-fir, cedar plantations (table 58) are 2 to 3 times denser with 1.4 to 1.5 times as much basal area for the same quality of site. Yields in French plantations also do not rival those of Douglas-fir or grand fir (Boullard 1974).

The higher yields in Britain (compare table 58 to tables 31, 56, and 57) probably result from inclusion of thinnings, the small top diameter, and the use of pure stands. The older natural stands were also much more dense and had more basal area than those used in Britain.

The overall volume growth figures for Coos County (table 59), indicate average annual increment of 5.9 m<sup>3</sup>/ha, which is 3.6 percent of the growing stock; saw timber growth is less—2.0 to 3.1 percent of the growing stock. Growth in more southern locations is slower at 1.4 to 2.4 m<sup>3</sup>/ha and about 1 percent of the growing stock for both cubic and board-foot volume.

Volumes present in old-growth forests are given in Chapter 4, primarily in tables 27 and 28. Based on recent cruises, mean volumes of 280 m<sup>3</sup>/ha still occur over areas the size of a clearcut in the best part of the range of Port-Orford-cedar. Single acres have yielded up to 1400 m<sup>3</sup>/ha (Gibson 1913) (see table 28). Some early estimates of volume and relative importance of Port-Orford-cedar in coastal Coos County appear to have been excessive. For example, Gibson (1913) reports an average of 210 m<sup>3</sup>/ha over 103 600 ha. Sargent (1881) estimated 18 193 m<sup>3</sup>/ha in an area 12 by 20 miles, certainly a misprint, which was not repeated in his later reports (1884, 1896).

Apparently only one volume table has been produced for Port-Orford-cedar (fig. 26).

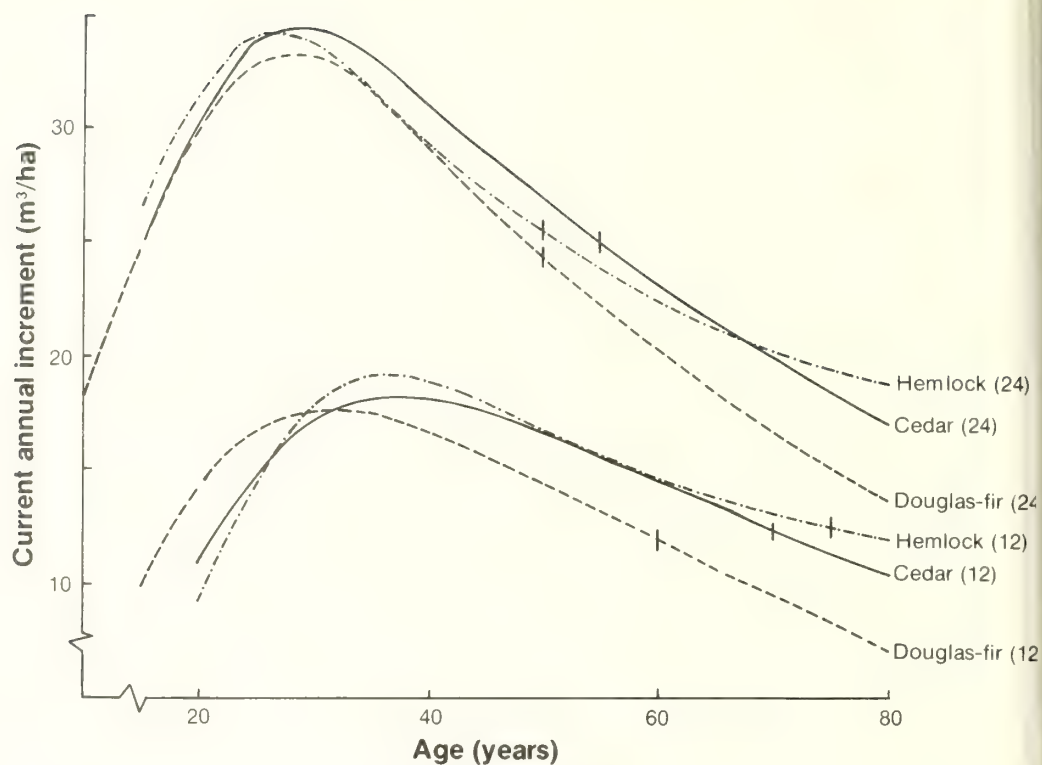


Figure 25.—Time course of current annual volume increment for Port-Orford-cedar and western redcedar (considered together), Douglas-fir, and western hemlock in plantations in Great Britain for good and poor sites (capable of producing a peak mean annual increment of 24 and 12 m³/ha, respectively). The vertical line indicates the time when the peak mean annual increment is reached (from data of Hamilton and Christie 1971).



**Table 59—Timberland area, cubic volume, and net annual growth of Port-Orford-cedar on unreserved timberland in three counties in Oregon and three counties in California**

Location	Area	Volume		Net annual growth <u>1/</u>
	thousand ha	thousand m <sup>3</sup>		thousand bd. ft.
Oregon:				
Coos Co.	17.8	2,910	105.8	13,436
Curry Co.	7.7	<u>2/</u> 255	<u>2/</u> 7.3	<u>2/</u> 760
Josephine Co.	1.6	198	2.3	250
California:				
Interior counties <u>3/</u>	2.4	538	5.7	1,100

1/ International 1/4-inch rule.

2/ Does not include volume or growth on National Forest timberland.

3/ Shasta, Siskiyou, and Trinity Counties, northern California.

Source: Bolsinger 1976; personal communication, 1980, T. O. Farrenkopf, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Species . . . . . PORT-ORFORD-CEDAR (*Chamaecyparis lawsoniana*)  
Unit of measure . . . . . Board foot  
Variables . . . . . D. b. h. and number of 16-foot logs  
Log rule . . . . . Scribner  
Scaling length for logs . . . 16 feet  
Stump height . . . . . 1.5 to 4.5 feet  
Top d. b. . . . . 8 to 15 inches  
Trim allowance per log . . . 0.3 feet  
Method . . . . . Frustum form factor  
Number of trees . . . . . 58  
Location of trees . . . . . Coos Bay Region of Southwestern Oregon  
Accuracy . . . . . Aggregate deviation 1.85 percent high  
Author . . . . . E. J. Hanzlik, U.S. Forest Service, Pacific Northwest Region  
Source . . . . . File report  
Year . . . . . 1934

D. b. h. (inches)	Volume in tens of board-feet when number of 16-foot logs is —											
	2	3	4	5	6	7	8	8	10	11	12	
12	9	14	18									
14	10	15	20	27								
16	11	17	23	31								
18	12	19	27	37	44							
20	13	22	31	42	51	60						
22		25	36	49	60	70						
24		29	41	55	68	81						
26		33	47	63	78	92						
28		37	53	70	87	103	123					
30		41	60	78	97	117	139					
32		45	67	87	108	130	154					
34		50	74	98	120	144	170					
36		55	81	106	132	158	185	215				
38			88	115	145	173	201	232				
40			95	126	158	187	218	248				
42			102	137	171	201	235	267				
44				147	184	217	252	286	381			
46				157	197	235	270	307	344	386		
48				167	210	252	288	330	370	416		
50				178	223	268	308	353	396	444		
52					236	285	328	378	423	472		
54					249	303	348	403	450	502		
56					262	318	370	425	476	531	582	
58					275	336	390	450	503	560	616	
60					288	353	412	473	530	590	648	
62						370	432	496	556	618	682	
64						388	452	520	582	650	716	
66						404	472	542	609	679	751	
68						422	493	566	635	708	782	
70						439	514	588	663	736	815	
72						455	534	612	689	766	848	
74						472	554	635	716	795	882	
76						489	575	660	742	824	914	
78						506	596	682	770	853	938	
80						523	616	705	796	882	980	

Figure 26.—Volume table for Port-Orford-cedar (Johnson 1955).

## Reproduction

**Vegetative reproduction.**—Reproduction of Port-Orford-cedar by layering occurs in sand dunes (Egler 1934, Hawk 1977), in some high-elevation forests, and in plantations (Iacovlev 1955), but the importance of layering seems to be small and localized. Production of adventitious roots allows the cedar to survive burial by sand (Cooper 1958, Egler 1934). On Blacklock soil near Coos Bay, branches of wind-thrown trees have developed into vigorous trunks with fuller crowns, better color, and apparently much faster growth than have trees from seedling regeneration (see footnote 10).

Rooting of cuttings, extremely important for horticulture, is relatively easy (Doran 1957, Larsen and Guse 1975, Welch 1966). Some cultivars, however, root much less easily than others (for example, 'Kelleris' with 58 to 78 percent of cuttings rooted vs. 'Triomf van Boskoop' with 0 to 11 percent) (Osterbye and Eriksen 1971). Cuttings with primary leaves root more easily than those with mature foliage (Masters 1896). One cultivar that is easy to root ('Fletcheri') has a low content of growth inhibitor and contains a substance that stimulates rooting of mung bean (Tognoni and Lorenzi 1972).

Cuttings may be taken in autumn or winter, although Bean (1950) suggests late summer. Some cuttings root better with hormone treatment (Tognini 1972); others root well without treatment. For western Oregon, cuttings should be taken from the terminal parts of branches, low in the crown (younger trees root better), after chilling has been completed and before growth resumes (that is, December to February).<sup>19</sup>

Cultivars vary in their response to hormone treatment, to misting vs. a plastic cover (Osterbye and Eriksen 1971), and to the effects of spacing (Kelly 1977). Wide spacing seems more important for those less easy to root. Wide spacing (30-45 cm<sup>2</sup> of bed per cutting) gives a higher percent of rooting and less disease damage, and the number of rooted cuttings produced is about the same. Root quality, fibrousness, and length of the cultivar 'Ellwoodii' increased considerably as rooting compost temperature rose from 15 to 20 °C, but increased only slightly from 20 to 25 °C (Whalley and Randall 1976). Port-Orford-cedar (cultivar 'Allumi') has been grafted to *Phytophthora*-resistant root stocks of other Cupressaceae, although success varied (Torgeson and others 1954).

**Flowering**—Sexual organs of Port-Orford-cedar are not segregated by crown position, as they tend to be on Pinaceae, but are borne on the same branches (Erspamer 1953, Rouane 1973). The indeterminate vegetative apex of small branches changes to a determinate reproductive apex whose growth ceases after cone formation. The transformation from vegetative apex to both types of reproductive apex begins after the production of a relatively uniform number of leaf pairs during a given season; however, the apices on the youngest, fastest growing branches produce seed cones, and the slower growing ones produce pollen cones (Rouane 1973). This results in a consistent pattern of distribution of the sexes on the branches (fig. 27).

<sup>19</sup>Personal communication, 1980, A.N. Roberts, Oregon State University, Corvallis.



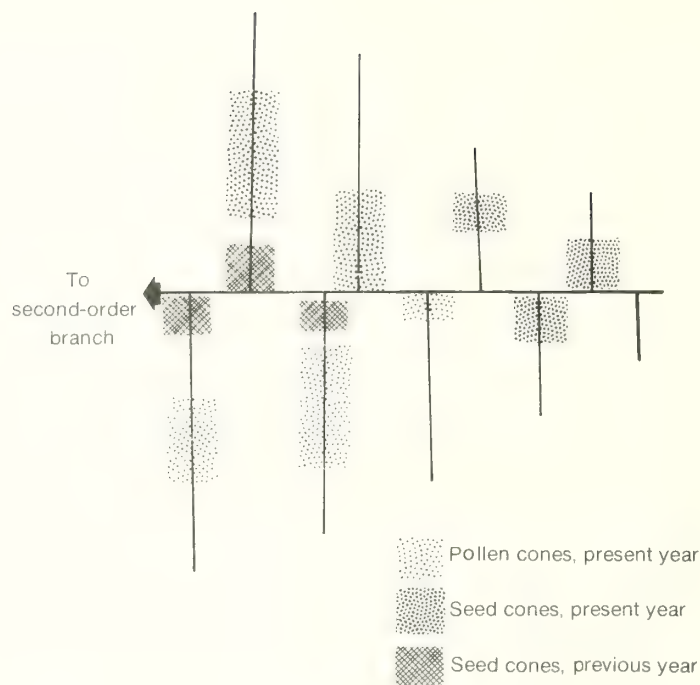


Figure 27.—A schematic diagram of the distribution of male and female reproductive organs on Port-Orford-cedar. The horizontal line represents the youngest part of the axis of a third-order branch, apex to the right. The vertical lines represent fourth-order branches. The zones along the fourth-order axes where branch systems with the two types of cones are inserted are shown. The female cones are actually borne on sixth-order branchlets, and the male strobili on the sixth and seventh orders. (Based on Rouane 1973, figs. 38 and 39, used courtesy Laboratoire Forestier de Toulouse.)

Reproductive primordia are formed in the late spring or summer. The initiation of pollen-cone primordia is well advanced by mid-June (probably beginning in mid-May) in Berkeley, CA, south of the native range (Erspamer 1953). The young pollen cones become visible in July, and initiation of sporophylls continues into August, with 10-12 pairs being produced. Sporogenous tissue is apparent in pollen cones in early July; its divisions continue into December. Male sporogenesis then begins and continues through February, with pollen shed in early March in Berkeley. In Japan, flower bud formation is in June and pollen formation is later, with meiosis in early March and mature pollen in early April (Hashizume 1973). Gianordoli (1962) records even later development: meiosis in early April and pollination in late April. There is little information from the natural range. In coastal Coos County, pollen shed has been noted as early as mid-March (see footnote 10), and at the southern end of the range in montane Humboldt County, CA, in late March and early April of one year (see footnote 11).

Pollen of Port-Orford-cedar is yellow to reddish, has no bladders, is half to three-quarters spherical, and has a granular surface. It has the lowest falling velocity of 33 tree species measured (Eisenhut 1961, Ho and Sziklai 1973). Diameters of the pollen are given as: 24 to 36 by 21 to 35  $\mu$  (mean 32 x 24) (Axelrod and Ting 1961); 26 to 31  $\mu$  (Eisenhut 1961); 32 to 38  $\mu$  (Camus 1914); and 26 to 43  $\mu$  (mean 36) (Hyde and Adams 1958). Pollen is larger than that of Alaska-cedar (Axelrod and Ting 1961). Optimum conditions for germinating pollen of several Cupressaceae (including Port-Orford-cedar) are a 2- to 5-percent solution of sucrose in distilled water, temperature of 26 °C, and high humidity (Razmologov 1964).

Seed cones represent a leafy shoot system with a reduced vascular system (Lemoine-Sebastian 1972), and the bract and scale fused. The number of ovules per scale varies, and some scales toward the apex are sterile (Aase 1915). No specific information about the time of initiation of seed cones seems to be available. Ovules were formed in August (Hashizume 1973); meiosis had begun early the following March in one study (Cecchi Fiordi and Maugini 1977) and by mid-April in another (Gianordoli 1962). Development is not synchronous among ovules in the same cone (Cecchi Fiordi and Maugini 1977, Gianordoli 1962). Pollination occurs a week or two after megaspore meiosis; fertilization follows in somewhat over a month (Gianordoli 1962). Pollination drops are present (Cecchi Fiordi and Maugini 1977, Gianordoli 1962). Seeds mature in the September or October following pollination.

Cecchi Fiordi and Maugini (1977) noted considerable degeneration of megaspores, which would reduce the percentage of seeds that were viable. Anatomical and cytological details of reproduction are described by Bonnet-Masimbert (1971), Cecchi Fiordi and Maugini (1977), Chesnoy (1973), Erspamer (1953), Gianordoli (1962), Hashizume (1973), and Lemoine-Sebastian (1970).

Initiation and sex of flower buds of Port-Orford-cedar can be controlled by adding hormones, specifically gibberellins (Bonnet-Masimbert 1971, Hashizume 1973). A single spray of gibberellic acid (50 mg/l) on the foliage induced flowering in plants less than 1 year old (Bonnet-Masimbert 1971). Ethrel enhanced the effect, but benzyladenine did not increase flowering (table 60). Photoperiod modifies flowering (tables 60 and 61). A long-day—>short day—>long-day regime after treatment is necessary for effective flower production. At least 2 weeks of long days are necessary to produce female flowers, and without the 2 weeks of short days following, pollen will not mature. The final long days are necessary for seed cones to mature and seeds to develop. Induced pollen cones may revert to vegetative growth in long days. Hashizume (1973) found treatment of 3- to 7-year-old trees with 50 to 200 p/m of gibberellic acid effective in inducing flowering when sprayed 3 to 5 times during June to August; 50 p/m was as effective or more so than higher concentrations. Treatment with gibberellins can reverse the sex of developing male flowers; ovules may form in the axils of the male sporangia, or male organs may differentiate into ovules (although no cones develop in the latter case) (Hashizume 1973). Such bisexual cones have also been found on untreated trees (Masters 1891).

**Table 60—Influence of various growth substances on flowering of 9-month-old Port-Orford-cedar**

Treatment <u>1/</u>	Long day---> Short day		Long day---> Short day---> Long day	
	Male	Female	Male	Female
- - - - - Percent flowering <u>2/</u> - - - - -				
"Tween 80"	0	0	0	0
+ GA	100	60	100	60
+ GA + E	100	80	100	100
+ GA + BA	100	20	100	80
+ GA + BA + E	100	80	100	80
+ BA + E	0	0	0	0

1/ GA = gibberellic acid (100 milligrams per liter (mg/l)); BA = benzyladenine (10 mg/l); E = Ethrel (200 mg/l); "Tween 80" is a wetting agent.

2/ Of five plants.

Source: Bonnet-Masimbert 1971.

**Table 61—Effect of photoperiod on the induction of flowering of 9-month-old Port-Orford-cedar by spraying with a solution of gibberellic acid (100 mg/l), benzyladenine (10 mg/l), and Ethrel (200 mg/l)**

Photoperiodic sequence	Male flowering		Female flowering	
	Percent of plants <u>1/</u>	Intensity <u>2/</u>	Percent of plants <u>1/</u>	Intensity <u>2/</u>
LD <u>3/</u>	100	+	0	
SD <u>4/</u>	90	++	0	
1 week LD--> SD	100	+++	0	
2 weeks LD--> SD	100	+++	20	+
3 weeks LD--> SD	100	++++	20	++
4 weeks LD--> SD	100	+++++	40	++
1 week LD--> 4 weeks SD--> LD	100	++	0	

1/ of ten plants.

2/ + = few pollen or seed cones; +++++ = many pollen or seed cones.

3/ LD = 16-hour days.

4/ SD = 10-hour days.

Source: Bonnet-Masimbert 1971.



**Seed production and germination.**—Open-grown container seedlings produce cones 3-4 years after planting. Most reports indicate that seed production begins early at 5 years (Macdonald and others 1957) to 9 years, becoming general by 20 years and continuing into old age (Hayes 1958, Zobel 1979). Flowering, with subsequent seed development, may be induced by gibberellin treatment of plants as young as 7 months (see section on flowering).

Seeds of Port-Orford-cedar are small, about 3-4 mm long, and weigh about 2 mg each (range, 0.76 to 5.7 mg; 175,000 to 1.3 million per kg) (Debezac 1964, den Ouden and Boom 1965, Harris 1974). Seeds are intermediate in size for the genus. The seed wall includes several resin-filled secretory pockets (Camus 1914). Seeds ripen in September or October, but are dispersed throughout the year, with peaks in autumn and smaller peaks from winter to spring (fig. 28). Roughly 50 to 60 percent fall by mid-January and 85 to 90 percent or more by May 1 (Hayes 1958, Zobel 1979). Seed production is less variable from year to year and there is less regional synchronization of seed crops than is characteristic of Pinaceae. No site produces a large crop 2 years in succession (Zobel 1979), but good seed crops occur at intervals of 3 years in Great Britain (Macdonald and others 1957) and 4-5 years in natural forests (Hayes 1958, Zobel 1979). Seldom does there seem to be a crop failure.

Cones yield about 20 percent of their weight in seeds (Harris 1974). Seed production ranged from 20,000 per ha to 4.6 million per ha in 30 seed crops; the average was lowest in the mixed evergreen zone (Zobel 1979, table 62). Seed production per unit of basal area was less variable among zones (table 62), with a productive seed year recorded from young (65 years old) and old-growth stands and from good and poor sites in all vegetation zones. Of 30 seed crops sampled, five exceeded 100,000/m<sup>2</sup> of basal area; six produced 20,000 to 60,000; six were 10,000 to 20,000; and 13 produced less than 10,000/m<sup>2</sup> basal area (but there were no crop failures) (Zobel 1979). There was some evidence that open-grown trees produce more seed than those in denser stands at the same site.

Seed are apparently not dispersed very far by wind (Camus 1914, Hayes 1958, Sudworth 1908); one to three tree heights seem the usual distance of invasion into clearcuttings, although this is highly variable. The small wings aid flotation in water, and water-dispersal may be of some importance in the streamside habitats the species often occupies.

Seed should not be dewinged and should be stored frozen and sealed with moisture below 10 percent (Harris 1974). In one case, viability of seed stored this way dropped from 56 to 43 percent in 7 years, while the viability of seed stored at room temperature was lost completely. Storage up to 16 years is possible (with 13 percent germination) (Schubert 1954).

Germination can be poor; it ranged from 11 to 44 percent for seed from seed traps at seven sites in 1975-76 (Zobel 1979). Germination was best for seeds released during periods of heavy seedfall, but was not correlated with differences in seed production among sites. Other seed collections germinated at about 50 percent or better (den Ouden and Boom 1965, Harris 1974).

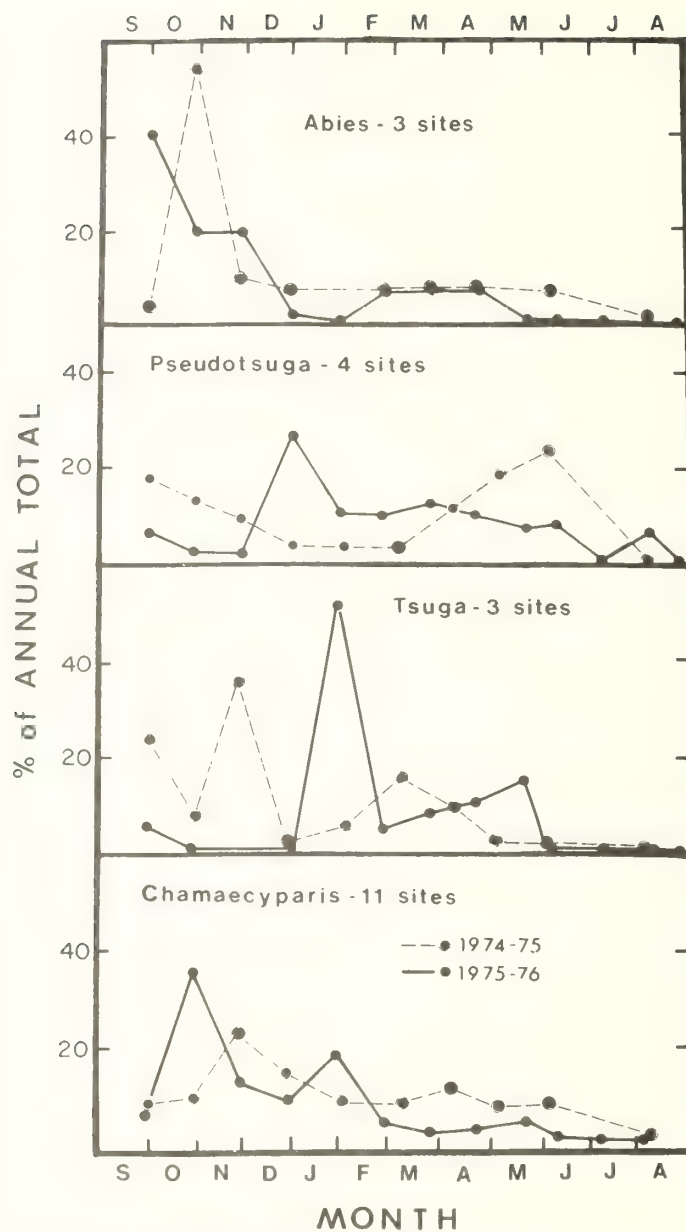


Figure 28.—Average percentage of total annual seedfall in 2 years for Port-Orford-cedar in 12 natural forests and for 3 associated Pinaceae (from Zobel 1979, used courtesy National Research Council of Canada).

**Table 62—Mean annual seed production for 3 years, expressed as seeds per hectare and per unit of cedar basal area, Port-Orford-cedar in natural forests**

Vegetation zone	Number of seed crops sampled	Seed production 1/	
		Per hectare	Per square meter of basal area
<hr/>			
		----- Thousand seeds -----	
<u>Picea sitchensis</u> + <u>Tsuga heterophylla</u> 2/	9	965 (72-4622)	32.3 (5.0-182.7)
Mixed evergreen	10	426 (20-1594)	48.4 (0.6-184.9)
<u>Abies concolor</u>	11	1071 (41-4511)	38.4 (1.3-154.9)
<hr/>			
All samples	30	829	40.2

1/ The range is shown in parentheses.

2/ Previous reports for the *Tsuga heterophylla* zone were 1.5 and 3.1 million per hectare.

Source: Zobel 1979.

Stratification seems not to be required for reasonable germination in most cases (Harris 1974) but may give slightly larger seedlings (Forestry Commission 1967). Germination is accelerated by red light (to 56 percent at 13 days compared to 32 percent at 27 days for the control) and retarded by far-red light (to 20 percent at 32 days) (Panasyuk and Vasileiko 1973). Indole acetic acid increases germination somewhat at 0.01 to 9.9 mg/l, and reduces it at higher concentrations; 2,4,5-T reduced germination at all concentrations tested (Fromantin 1958a, 1958b).

In a Taiwanese nursery, germination required an average of 16.4 days (range of 8 to 26) after planting, the longest of five *Chamaecyparis* species tested (Liu and others 1975). A similar time is required for seeds germinated in the laboratory at 17-20 °C. Most germination of seed planted under an intact native forest was in early to mid-June; 9 percent occurred from mid-June to mid-July; and 2 percent was later (Zobel 1980). In Washington, Port-Orford-cedar germinated in the third and fourth seasons after sowing (0.5 percent each year compared to 1 percent the first year), the only conifer in the test to do so (Isaac 1940). No sign of significant delayed germination occurs in more extensive seeding trials (Zobel 1980).

Compared with its usual associated conifers, Port-Orford-cedar is intermediate in age of first reproduction; is intermediate in earliness of seed release; has large seed crops but moderately small seeds; has moderate seed longevity; and has a low stratification requirement (Minore 1979). It produces more seed (relative to its basal area) than do Douglas-fir and white fir on the same sites but fewer than western hemlock. There is much less difference among these species when production of seed mass is considered (Zobel 1979). Seedfall of cedar is generally distributed more evenly over the year than that of associated Pinaceae (see fig. 26). Considerably fewer seeds of Port-Orford-cedar fall per hectare than are reported for Asian *Chamaecyparis* and for *C. thyoides*.



**Seedling establishment.**—Seedlings produce two cotyledons, then two primary leaves at right angles to the cotyledons, and then whorls of four primary leaves each. Cotyledons were 0.62 cm long (range 0.3 to 1.0 cm) by 0.1 cm wide and were the longest and narrowest of the species tested by Liu and others (1975). Camus (1914) gives 0.8-1.2 cm as the length. Port-Orford-cedar required 183 days (range 148 to 229) before secondary leaves appeared and produced 46 primary leaves (range 36 to 64) (Liu and others 1975).

Although seedling establishment can occur on natural forest floor, some soil disturbance greatly accelerates it. Germination, establishment, and seedling growth in natural forest understory are better on spaded plots than on those with litter removed, burned, or left intact (Zobel 1980). No seedlings survived the second season on plots with the litter removed or burned. By the end of the third season, an average of 5 percent of the original germinants were alive on the spaded plots and 6 percent on intact litter. None survived, however, under a young, dense forest where initial seedling establishment had been most successful.

Seedling establishment after clearcutting in the northern end of the range is adequate within a reasonable distance of a seed source. James and Hayes (1954) recommend that clearcut units be less than 200 m across; alternatively, shelterwoods with considerable remaining cedar can be used if natural seedlings are relied on for regeneration. Cedar establishment was limited by dense ground cover, but James and Hayes (1954) found no significant effect from other site conditions they measured. Cedar was generally more prevalent in regeneration than in the original stand. Recent observations throughout the range confirm the results of James and Hayes for most areas. Effective natural regeneration occurs within about 80 to 110 meters of a seed source in most recent clearcuttings. The species appears to reproduce itself at least in proportion to its original importance. In the southern coastal area, the cedar is establishing higher on the slopes than it did in the original stand. Silviculturists generally consider Port-Orford-cedar to be a dependable reproducer close to a seed source, although one report describes its exclusion by Douglas-fir (American Lumberman 1911).

Establishment in natural forests appears to have occurred, at least to some extent, in waves following disturbance (Hawk 1977, Viers 1982), probably fires. There are several size classes of Port-Orford-cedar in some forests in which both fire-intolerant and shade-intolerant species have only one size class; this suggests that cedar regeneration continues beneath the forest canopy. Often the largest cedars have multiple fire scars.

Data from Hawk's (1977) sampling were used to try to relate the amount of reproduction of Port-Orford-cedar in natural forests to site and stand variables. There were significantly fewer seedlings and saplings, and they had less cover on steeper slopes, on sedimentary rock types, and on soils developed on alluvium, than in other conditions. Use of these variables accounted for only about 15 percent of the variability in numbers and cover of reproduction.

In American nursery practice (Harris 1974), the seed is sown in spring at 322 to 538/m<sup>2</sup> and covered by 0.3 to 0.6 cm soil. Stratification of seed and shading until midseason are recommended. Bare-root seedlings were grown as 1-1 or 2-0 seedlings in the United States (Harris 1974, Ruth 1957). Container-grown stock 1 season old and 20-30 cm tall has recently been used successfully.

British practice (Macdonald and others 1957) involves broadcasting seeds at 13.5 g/m<sup>2</sup>. Seedlings were lifted after the first year in heathland nurseries or after the second year in others; in some cases 2-1 plants have been used (Harris 1974). Three-year-old seedlings were planted in New Zealand (Streets 1962) and even older ones have been recommended (Schenck 1907). No special nursery practices are necessary for the species.

Seedlings may be stored successfully during the period March to July; 2 °C is a more favorable storage temperature than -2 °C (Aldhous and Atterson 1963). In Oregon, seedlings planted after 2 months in cold storage grew and survived as well for the first 10 years as those planted without storage (Ruth 1957); seedlings planted in November survived better than those planted in April (Krygier 1958).

Port-Orford-cedar is cheap to grow and easy to move and establish in Great Britain (Ackers 1947). In Denmark, first-year survival in 13 plantations was 91 percent—among the best of the western North American conifers used. Establishment and maintenance expenses for the first 10 years were lower than for grand fir and Douglas-fir, but higher than for lodgepole pine and Sitka spruce (Holmsgaard and Bang 1977).

## Seral Status

Throughout most of its range, Port-Orford-cedar seedlings can establish themselves in quantity during early stand development, after disturbances in stands, or under an intact, old-growth canopy. The species appears to be unusually effective in this dual role of early seral invader and shade-tolerant climax species. Near Coos Bay, it was the first tree to reappear after extensive fires (Sargent 1884).

Its role as an invader of disturbed areas is also apparent on most clearcuts where a seed source existed. Establishment continues after initial crown closure in clear-cuttings, but ceases after a few years in dense stands, where understory may become virtually absent. As the stand ages, establishment of this shade-tolerant tree occurs again (see table 43). In old forests, all sizes of classes of cedar are present in all communities (Hawk 1977). Some stands have two or more important size classes, which appear to have resulted from repeated fires (Hawk 1977). One exception occurs on some higher elevation ultramafic rocks near Powers, OR, where dominant cedars have an understory almost entirely of western white pine, and little cedar establishment has followed a cut that removed much of the overstory.

A contrasting behavior is recorded in the California montane forest (Sawyer and Thornburgh 1977). Colonizing ability (the ability of species to reestablish quickly on suitable sites after fire) is listed as low for Port-Orford-cedar—below that of mountain hemlock, Douglas-fir, white fir, Shasta red fir, and Brewer spruce.

Franklin and Dyrness (1973) emphasize the early seral role of Port-Orford-cedar but do not believe it capable of competing in the shade. Our arguments to the contrary are presented in the section, Shade Tolerance.



## Competitive Ability

The attribute of competitive ability is defined by Sawyer and Thornburgh (1977, p. 722) as "the capability of individuals of a species to grow and achieve dominance in competition for light, water, nutrients, and space with individuals of other species." Port-Orford-cedar is credited with high competitive ability on granitic and metamorphic parent material in the western *Abies concolor* zone of the montane forests in California, on wet to wet-mesic sites; only white fir is higher in this ability. In mesic sites on the same substrate in the higher Californian *Abies magnifica* zone forests, it has moderate competitive ability on mesic sites—lower than Shasta red fir, Brewer spruce, and mountain hemlock but higher than white fir. A somewhat different relationship apparently holds for the northern end of the range, where Port-Orford-cedar is almost always smaller than Douglas-fir by the time the tree reaches commercial size.

Another aspect of competition is the effect that a species has on its neighboring trees. For example, does the presence of a moderate to small amount of Port-Orford-cedar affect the productivity of the Douglas-fir in a stand? The definite opinion of several forest managers in Oregon is that Douglas-fir volume will not suffer from the presence of some cedar in a stand; some thinning prescriptions presently in force are based on this perception. This failure to interfere with Douglas-fir growth may result from an enhancement of soil properties by the cedar litter, from cedar's slower early growth, and cedar's lower (shade tolerant) crown.

## Factors Limiting Distribution

Determining what attributes of the environment and the plant limit the distribution of a species is complicated; an unequivocal or universal answer may be impossible. Enough information is available, though, to suggest promising working hypotheses for Port-Orford-cedar, and we will review and somewhat expand upon those discussed by Zobel and Hawk (1980). The patterns of distribution vary with the scale of the area being considered; we present suggestions for four levels of scale—microenvironmental, topographical, regional, and geographical.

**Microenvironmental level.**—Little information is available about control of establishment of single individuals of Port-Orford-cedar or even about distribution patterns at the microenvironmental level. Observations show that Port-Orford-cedar seedlings are more common on logs than on the forest floor in some sites; in other sites, the opposite is true. Some canopy gaps support much cedar, while other gaps are dominated by other species to the exclusion of cedar; and cedars often seem to have established outside the gaps. Hypotheses for which we have some evidence (Zobel 1980, Zobel 1983, Zobel and Hawk 1980) are: (1) Soil moisture must be available at or near the surface all summer, both for initial establishment and later for good growth and reproduction. Season-long high water potential is probably necessary because germination is delayed until June; because cell division, twig elongation, and exposure of new foliage continues throughout the summer; and because of the late-summer development in the reproductive organs, which are initiated in early summer and emerge from the protection of surrounding leaves within a month or two. (2) Young dense stands and some microsites in old-growth forest are too dark for cedar to survive. (3) Disturbance of the mineral soil increases initial establishment, survival, and growth.

**Topographic level.**—Throughout much of its range, cedar seems clearly limited to topographic situations that assure a consistent water supply: areas with moving subsurface or surface water of all sorts, lakesides, beds of intermittent streams, gullies, slumped topography with seepage, and slopes with a sufficient watershed above to maintain seepage. Measurement of water potential of conifer saplings across several such features demonstrated a gradient away from the concavity. Cedar were limited to areas with late summer potentials above  $-11$  bars before dawn. Cedar can be limited primarily to stream valleys and lower slopes (see fig. 12) or to northerly slopes, especially those at low elevation.

Port-Orford-cedar is limited locally to soils with higher K and Mg availability than is western redcedar.

**Regional level.**—Much of the distribution of Port-Orford-cedar at scales larger than the local topography is associated with geologic pattern (see fig. 1). The concentration of cedar on ultramafic rocks is obvious almost throughout its range, and cedar is limited to ultramafics in many areas. The relative importance of cedar and its associates differs among geological substrates, as indicated above and in the community descriptions.

There appear to be several reasons for the relatively greater abundance of cedar on ultramafic rocks. It has lower concentrations of P, K, and, especially, N in its xylem sap, leaves and litter than do Douglas-fir, hemlock, and some other conifers grown in the same environment. It maintains a higher Ca:Mg ratio on ultramafics and produces litter high in calcium. It may require higher Mg than occurs in some nonultramafic soils. Cedar seems better adapted to grow on these soils than do the dominants in more fertile areas; furthermore, its competition for water is reduced on ultramafic areas. Where cedar grows, the weathering of the ultramafic rocks has produced a dense layer of fine clay that creates a perched water table and consistent seepage. The saturation sometimes associated with these areas further excludes tree competitors. On ultramafics, then, water becomes concentrated enough to allow the cedar to grow, and its most effective competitors are excluded or have their density and vigor greatly reduced. In more humid climates, at low elevations where western hemlock or redwood can grow, or at higher elevations inland, cedar is not restricted to ultramafic rocks, and is most important and largest on the most productive soil types.

Increased humidity compensates partially for soil moisture, and the species grows on more convex topography near the coast and at high elevations. Even so, it has an uneven distribution over the topography. In the Coos County Forest, cedar was originally concentrated not only in wet glade lands, but also in other areas not obviously distinct from those without cedar (see footnote 9). Cruise data (by 16.1-ha blocks) and topographic and geologic maps from the former Port-Orford-Cedar Experimental Forest were analyzed using multiple regression techniques to determine what factors were significantly associated with the volume of cedar in old-growth forest. Port-Orford-cedar volume decreased significantly at higher elevations, on steeper slopes, and on southwest aspects, and was significantly higher on Eocene sedimentary rocks than on the other four rock types. These factors, however, accounted for only 25 percent of the variability. Despite the high proportion of "unexplained" variability, the factors that were significant agree with other observations of species' behavior relative to landform.



**Geographic level.**—One problem with trying to “explain” geographic limits is that the descriptions of the geographic range are too simplistic, are incompletely documented, or disagree (see Chapter 2). Cedar may have been eliminated recently from certain areas by harvest and management practices or by disease—a problem that will increase in the future. Even so, some suggestions about range limitation can be made.

Precipitation and its ratio to evaporation drop drastically east of the range; sufficient microsites wet enough for the cedar probably disappear. Near the south end of cedar's range, the ultramafic substrates usually associated with the occurrence of cedar disappear from major river valleys and high coastal ridges—locations where, farther north, cedar will grow.

At the north end of the range there are no single-factor explanations that are supported by evidence. A complex hypothesis can be considered, however: The vigor of the cedar's competitors increases rapidly north of Coos Bay, and factors favoring the cedar remain stable or decline. To compete, the cedar must grow faster, which seems to require a longer period of stem elongation. Trees in the open near Coos Bay already elongate for 5-6 months; this may be the limit to their season of growth as imposed by either environmental or internal factors. There are two possibilities for environmental conditions at the north end of the range that do favor Port-Orford-cedar: (1) The coastline from Coos Bay to Port Orford is oriented at  $21^\circ$  from the more usual coastal direction of north-south. Summer winds, predominantly from north to northwest, strike the coast here at a greater angle than elsewhere, perhaps forcing marine air farther inland. The lowlands around Coos Bay and the northwesterly opening of the Coquille River drainage allow easy movement of marine air inland during the summer. Observations of cloud and wind patterns support the idea of a summer marine influence being important in the southern Coquille Valley. (2) Sediments forming the Coast Range at about Coos Bay and south were derived from the Klamath Mountains, which have abundant ultramafic rocks. Farther north, sediments came entirely from the volcanic terrain to the east. Any residual ultramafic influence in the soils, which may favor the cedar at the northern end of its range, disappears northward.

Another possible factor affecting the northern limit is increased competition from western redcedar, whose importance may increase northward in response to declining frequency of fire (Edwards 1983). Edwards also notes that the expansion of importance of Douglas-fir, apparently the major competitor of Port-Orford-cedar, is geologically recent.

**Changes with time.**—The distribution and importance of cedar differ depending on the seral stage and stand age; a major influence seems to be fire. In some areas, cedar is presently invading clearcuttings, which appear to be drier than the habitat in older forests. More frequent fires on drier sites may have previously eliminated cedar from drier sites, and the local distribution appears to be expanding with clearcutting in the absence of fire (see footnote 4). In moister, old-growth forests, repeated but less frequent or less severe fires appear to have allowed cedar to increase through time. The old cedar trees survived better than other shade-tolerant species, and cedar seedlings invaded under the remaining canopy more effectively than did other fire-tolerant conifers. In a few areas, however, stands with repeated fires in the past have large survivors but little cedar reproduction.

In 1907, C.A. Schenck noted that "In the sapling stage, fungi seem to play havoc in the plantations, a fact which may explain the small range of the species" (p. 60). To what area or fungus he is referring is not clear, however. *Phytophthora lateralis*, presently the only major disease problem in the native range, was not reported until 1952 (see Chapter 7), nor is there strong reason to believe it was important or even present earlier.

**Comparison with other conifers.**—Port-Orford-cedar appears to react differently to changes in environment than the more widely distributed Pinaceae with which it grows (Zobel and Hawk 1980). It disappears with reductions in water availability that do not affect cooccurring species. It does grow, however, throughout temperature ranges and across soil-type boundaries that cause major changes in populations of other conifers.

**Summary.**—The primary factor of importance in cedar distribution appears to be a consistent summer water supply. Topography, geology, and climate apparently have their effects by influencing water supply. Temperature alone seems to have little effect on the local or geographic ranges, except perhaps in a few high-elevation areas. Such a simplistic answer to a complex question may eventually prove to be quite misleading; for example, many of the local details of distribution are not described well and the apparent requirement for water may have been magnified by past effects of frequent or intense fires—but this is the hypothesis that best fits our present data.

The only serious pest in the natural range of Port-Orford-cedar is *Phytophthora lateralis* (see Chapter 6), a fungus that causes a fatal root rot of the tree. Since 1952, this disease has spread throughout much of the area that supports commercial forest. Unless management techniques are developed specifically to take into account the effect of the fungus, and are applied rigorously and consistently, there can be little or no commercial future for Port-Orford-cedar beyond harvest of existing stands. Information about the disease is essential if managers are to suppress the disease and produce future rotations of cedar.

We do not know the exact size of losses resulting from the Port-Orford-cedar root rot epidemic because of unique features of the commodity, the market, and the economy. Port-Orford-cedar at one time was particularly important to the maritime Pacific Northwest, outside its native range, as a lead item in the large export and domestic ornamental nursery industry. This industry, without cedar, was worth \$23,000,000 in 1969 (Loy and others 1976). Within its range it is the most valuable timber species. The ornamentals and timber industries have suffered successively from the root rot.

## Chapter 7: Pathology and Control of Port-Orford-Cedar Root Rot

### Damage Caused by *Phytophthora lateralis* Root Rot

It is essential to understand the importance of Port-Orford-cedar for residential and farm plantings if one is to appreciate the root rot epidemic and its threat to the forest. Before the epidemic, ornamental Port-Orford-cedar were grown in hundreds of private nurseries, and seedlings were available at little or no cost from public nurseries. Nursery stock alone constituted a significant population of cedar, and trees used in landscape and specimen plantings, hedges, and windbreaks resulted in high densities of cedar in much of western Oregon, Washington, and British Columbia, north of the native range. In terms of their disease vulnerability, these plantings resembled a forest. This artificial forest was largely destroyed by *Phytophthora* root rot, its effect aggravated by urbanization. Preceding collapse of cedar production, direct losses to nursery owners from crop failure in Oregon approximated \$500,000<sup>20</sup> through the 1950's. Indirect losses because of replacement of trees and costs of shifting to alternative crops probably were as great as the direct losses. Less tangible losses have been replacement costs met by individual property owners, depreciation of property values, and reduction in environmental quality.

Within the native cedar region, losses of timber are large, diverse, and as with the horticultural trees, frequently not tangible. Trees of all ages are quickly killed by root rot. The loss has been primarily from disease spreading into commercial stands where it is measured by value of trees killed and, more recently by cost of disease control. Few managed young stands exist because the species was silviculturally abandoned for two decades as a result of the threat of disease.

Mortality in old-growth timber is estimated to have peaked in the early 1970's at just under 10 million board feet annually and since then to have gradually declined to about 5 million board feet.<sup>21</sup> The reduction has been primarily due to depletion of the resource, but also to slower spread of the disease onto less vulnerable sites.

Prices of killed timber must be sharply discounted below green log prices. After the bark loosens, about 3 years after death, logs lose their value for export, especially if bark has been lost and the wood has been exposed to the sun. Sun-checked logs are worth less than half the value of a sound log.

Mortality in commercial young growth has occurred mostly on the gently rolling, narrow, 100-mile coastal strip between Hauser and Gold Beach, OR. The forest reclaimed much of the land after logging between 1880 and 1930 and widespread grazing, with new cedar densities on former cedar sites approximating those of the original forest. Because of poor market conditions, this young forest was not commercial in the 1950's when root rot first entered the region. Thirty years of additional growth and price increases makes most of this remaining timber commercial today.

<sup>20</sup>Personal communication, 1981, William Wheeler, Oregon Department of Agriculture, Salem.

<sup>21</sup>Personal communication, 1978, personnel of Coos Bay District, Bureau of Land Management; Georgia Pacific Corporation; and USDA Forest Service.



Urbanization and small-tract subdivisions have spread *Phytophthora* throughout the young-growth cedar forest since 1950 (Roth and others 1957, 1972; Kliejunas and Adams 1981). Sixty-percent loss seems a reasonable estimate today. The cash value of this mortality, because of low prices for small logs (see Chapter 8), has not been great. Depreciation of real estate values has been substantial. These losses have, however, been partially compensated by regrowth of stands of adequate density but of less valuable species. The major loss is in expectation values (Baxter 1952) of the potentially valuable cedar. High-quality, second-crop logs from this coastal cedar might have maintained the market, though at a lower level, after the remaining 30-year supply of old growth on public lands is harvested, and partially bridged the gap until production on major holdings can be brought under sustained yield with effective disease management. It is not unreasonable that the forest manager have high expectation values for the young stands; their destruction represents a real and substantial loss.

Much regeneration has been killed, often on sites where the best stands once stood, where the fungus was introduced from contaminated roads or by elk or cattle. Again, these losses are only of expectation values, which are difficult to estimate. Even without root rot, young cedar, because of its comparatively slow growth, is valued differently by various managers, and a value assigned by the same manager may change with time. The presence or threat of root rot makes it even more difficult to establish appropriate management objectives for young cedar stands. On good soils, all diseased sites (except ravines and swamps) are adequately stocked with faster growing alternative species. Even though timber of these species is worth much less per unit, it is difficult to place a cash value on the dead cedar regeneration or, in fact, to claim that there has been a loss. When appraising regeneration losses, one must remember, however, that (1) good cedar has usually been worth substantially more than the more common conifers, (2) the highest unit area return in the region results from the proper mix of Douglas-fir and cedar, and (3) on most ultramafic sites, possible alternative species, where they exist, grow less well than cedar and are less valuable. Encouragement of regeneration and retention of young growth seem justified.

Two additional items need mention when considering damage from root rot. The serpentine mountains of the native Port-Orford-cedar region are floristically unique and particularly beautiful. Port-Orford-cedar is the outstanding tree on these sites and in some cases is the only species of commercial quality. When these sites become contaminated, they may no longer be regarded as commercial timberland for Port-Orford-cedar; the accompanying aesthetic loss is impossible to evaluate.

Manufacturing in the Port-Orford-cedar region is preponderantly of Douglas-fir; cedar is exported. The disparity in value between the two species is so great that bidding on timber sales with mixtures can become highly complicated and costly to participants (see Chapter 8). Some decision makers in the forest industry have regarded the cedar as a nuisance and have been unsupportive of efforts to protect it against root rot or to manage it. These attitudes may have contributed to understatement of root rot losses, to lack of support for disease control, and to carelessness in woods operations.



## Background for Root Rot Control

There are no cures for root rot. Genetically resistant stock is not available. Tests of chemicals found to be effective against other species of *Phytophthora* are incomplete. If chemicals should function against *P. lateralis*, their cost and special application may limit their use in the forest.

Limiting or preventing cedar root rot must, for an indefinite time, depend on suppression through management. The only disease management strategy at this time is to enable cedar to escape infection. To make loss reduction by disease escape effective, management must be dedicated to the long-term goal, and silviculturists must thoroughly understand the tree and its environment, and how these interact to affect the disease.

**Recognizing cedar root rot.**—Root rot may be identified: (1) by the rapid death of individual trees, (2) by the distinctive symptoms, (3) by the characteristic distribution of disease through the forest, and (4) by the exclusive occurrence on Port-Orford-cedar.

Rapid death of the crown is distinctive and involves a loss of luster and a change in color from the normal green or blue-green to gold, bronze, reddish brown, and finally dull brown. Yellow tones, rather than bronze, may be more common in the southern part of the range. Damage to tree roots by the moisture-dependent, low-temperature fungus peaks during the cool, wet season, but crown symptoms lag because of prevailing high humidities. Moisture stress in late spring and summer results in the simultaneous death of the entire crown. Trees die without thinning of the crown.

Root symptoms arise as a result of fungal growth across root grafts between healthy and diseased trees (Gordon and Roth 1976) or, most often, following direct fungal infection of the tips of fine roots. The fungus grows from the tips through the succulent tissues toward the root crown. Root tips lose their luster, become water-soaked and soon rot. Fine, suberized roots become dark brown, then almost black. They too rot within a few months, leaving a much depleted root system. Bark of main roots darkens somewhat or occasionally appears purplish. Discoloration of inner bark and cambium extends up the main roots through the root collar into the lower bole for a distance of roughly two stem diameters. This discoloration is a uniform rich brown ending abruptly along its upper margin, sometimes in short spires, against healthy, bright, cream-colored inner bark. Inner bark of the entire bole and branches finally browns following crown desiccation.

Root symptoms are most apparent in winter and spring. The color is lighter in summer and the transition from infected to healthy tissue less definite. The dead tissues may be dry and hard. Although the summer condition resembles the usual effect of *P. cinnamomi*, confusion of the two is unlikely because *P. cinnamomi* root rot is absent from Pacific Northwest forests.

Care is needed to avoid confusing root rot symptoms and attack by *Phloeosinus* spp. bark beetles. Crowns of beetle-infested trees thin over several months and fade unevenly toward yellow, with the foliage often assuming a green-yellow-brown tweedlike mixture. Exit holes are numerous in the bark. Blazing the trunk bark discloses galleries behind the exit holes and irregular patches of dead, brown inner bark scattered through the cream-colored living tissue. Dust from recent attacks is evident on the bark and at the base of the tree. Root bark remains bright for some time.

Most of the distinctive, uneven distribution of root rot in the forest is accounted for by spotty introduction of the fungus superimposed on uneven distribution of the cedar. This is especially evident in the southern part of the range where cedar, like the fungus, depends heavily on seepage. Disease centers are most frequently correlated with wet spots. In the northern part of the range of cedar, where soil moisture is sufficient for cedar over more of the landscape, the irregular pattern of occurrence is more affected by the machines and animals that carry the fungus and by subsequent movement of surface water.

When contaminated carriers enter a water course, ditch, stream, lake, or bay, the aquatic fungus can become established on cedar where the roots are below the flood level. These influences result in scattered patches of infected trees connected by strands of damaged trees (USDA Forest Service 1975). No other pest produces this netlike pattern in the forest (most easily observed in aerial photographs).

**Spread of root rot.**—*Phytophthora lateralis* lives in infected roots and wet soils and moves when these are moved. Spores released by the fungus are readily transported in flowing and splashing water. Spore transport through the air is so rare as to be irrelevant to disease management (Trione and Roth 1957). During wet weather, the important carriers are elk, cattle, and machines (construction equipment, road maintenance equipment, and logging equipment, trucks and off-the-road vehicles). There is abundant circumstantial evidence that all these carry the fungus. In dry weather, the main carriers are hauled earth, gravel, and soil-bearing debris.

Transport of ball-and-burlap container and nursery stock and garden plants is particularly hazardous when these have grown in soils following diseased cedar. Because symptoms are so conspicuous, movement of the fungus in diseased cedar stock is less likely, except possibly for larger ornamentals where development of foliar symptoms may be delayed. Small cedars die so quickly that trouble is soon evident. Whether from a nursery or from the wild, infected trees usually are culled and do not move. Healthy but contaminated stock from the same sources is particularly dangerous. Boots of workers in muddy operations, such as salvaging killed timber or cleaning ditches, can transport the fungus, but boots of personnel performing ordinary forestry functions probably are not a threat.

**History of the disease.**—*Phytophthora lateralis* is an aquatic fungus active at low temperatures well suited to the soils and climate of the Pacific Northwest (Trione 1959, 1974).

The first report of *Phytophthora* root rot was in 1923 in correspondence by the Malmo Nursery in Seattle, WA, with the Pacific Northwest Forest and Range Experiment Station, Portland, OR:

We are sending . . . plants which are affected with a fungus disease which completely encircles the crown of the root, thus killing it. . . . We have already lost several thousand dollars worth of cypress. . . . We sent species for examination . . . about a year ago . . . the disease prevails throughout the whole Northwest, killing cypress in the private gardens as well as in all nurseries, causing vast loss, as this Lawson cypress is used very much here. . . . So far in our nurseries the disease has attacked only . . . *Chamaecyparis* (referred to as cypress by the trade) *Lawsoniana* (Port-Orford-cedar), *C. lawsoniana* erecta viridis, *C. lawsoniana* alumii, monumentalis, etc. . . . the disease [has] never been noted to have been overcome by the plant. . . . It would probably be worthwhile to have a thorough study made of this disease as if it goes on unchecked it will eventually kill all cypress, including the Lawson cypress timber stands of Oregon.<sup>22</sup>

J. S. Boyce, Station pathologist, visited the Malmo Nursery several times in 1923, making the following observations, among others:<sup>23</sup>

. . . any disease which is so virulent as this one appears to be is potentially dangerous . . .  
. . . It may interest you to know that what seems to be the same disease has done considerable damage to a hedge of Port-Orford-cedar here in Portland.  
. . . All the stock is propagated from cuttings and pot grown before being set out in the nursery. Much of the stock at this nursery in the past came from France. In most cases, the other varieties are grafted to a *C. lawsoniana* root stock.

This correspondence shows that the disease was widely distributed in cedars in nurseries, landscapes, and windbreaks by the time it became known to pathologists. Although the trouble was initially reported as a "fungus disease," two decades passed before the cause was confirmed and the fungus described (Tucker and Milbrath 1942). By this time, the disease was epidemic in the ornamental cedar industry and in hedges and windbreaks.

In 1952, 30 years after the alert was given in the Malmo correspondence (see footnote 22), the disease appeared in the native range of Port-Orford-cedar (Roth and others 1957). There was active commercial development in southwestern Oregon in the 1950's, and the fungus was rapidly distributed by construction and landscaping. It quickly appeared along the roads and the banks of streams that crossed the roads and along woodland stock trails. Within 3 years, root rot was conspicuous along the populous coastal strip and up the settled river valleys of Coos and Curry

<sup>22</sup>Unpublished, typed report, Nov. 7, 1957, "Early History of Port-Orford-Cedar Root Rot," by John Hunt, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 2 p.

<sup>23</sup>From unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.



Counties.<sup>24</sup> Less intensive activity and topography adverse to movement of the fungus delayed spread inland into the remaining commercial forest and high mountains. Several locations were noted within the Siskiyou National Forest by 1960 and one at Gasquet, CA.<sup>25</sup> Spread is continuing there where it accompanies road construction and logging, and, at least in some sites, appears to be aggravated by an increasing elk population.

**The origin of *Phytophthora lateralis*.**—The origin of *P. lateralis* is unknown; however, three views predominate: (1) that *P. lateralis* is endemic within the cedar region, (2) that it was introduced from Europe or Asia, and (3) that it is endemic in the Pacific Northwest outside the Port-Orford-cedar region.

Root-infecting fungi can live in a biologic community without causing conspicuous symptoms in their host (Garrett 1981). *Phytophthora* is well known for such behavior. For example, Middleton and Baxter (1955) report isolating *P. cactorum*, *P. cryptogea*, *P. parasitica*, and *P. cinnamomi* from roots of native plants without symptoms in pristine locations within the Port-Orford-cedar region. These authors may have misjudged the pristine nature of their location. They overlooked the extensive grazing and mining activities that occurred in the region around the turn of the century. Particularly suspect are the extensive transport of water for both mining and irrigation and the ubiquitous kitchen gardens of the Chinese miners of the era. *Phytophthora lateralis* was not among the fungi recovered nor would we have expected it; no host for it has been found except Port-Orford-cedar, and cedar shows symptoms soon after infection.

It seems equally unlikely that the fungus has been reactivated by human activity in recent decades to become a troublemaker. This has occurred with some plant diseases (Garrett 1981) and is reported for *P. cinnamomi* (Shepherd 1975). If the fungus were to reappear because of disturbance, it should have emerged long before 1950 as parts of the cedar region were subject to disturbance (farming, logging, road construction, mining, and urbanization) for 100 years before the first trees died from *Phytophthora*.

It is more reasonable to accept the fungus as introduced. It might have immigrated unassisted to southwestern Oregon from the infested Willamette Valley, but this seems unlikely for a fungus having waterborne rather than airborne spores. The valley and the Port-Orford-cedar regions are separated by an uninterrupted forest of immune Douglas-fir, precluding root-to-root spread, and by the Coast Range, which would prevent migration of the waterborne spores. The initial occurrence of root rot near recent landscaping indicated that spores were probably introduced with nursery stock grown in contaminated soil outside the cedar's range.

<sup>24</sup>Processed survey reports, 1956 and 1959, "Port-Orford-Cedar Root Rot Survey: and *Phytophthora lateralis* on Port-Orford-Cedar," by John Hunt, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

<sup>25</sup>Collection by Lewis F. Roth.



Arguments that *P. lateralis* was introduced from Asia are based on the high resistance of the Asiatic species of *Chamaecyparis* to root rot. Scientists recognize that disease resistance may emerge through coexistence of a species with its pathogens over thousands of years. Consequently, the land of origin of resistant trees is a good place to seek the origin of their pathogens. In spite of the advanced level of *Phytophthora* research in the Orient, however, *P. lateralis* has never been reported in Japan or Taiwan.

The notion that *P. lateralis* was introduced from Europe seems even less probable than introduction from Asia. The many competent European mycologists, including *Phytophthora* specialists, have never found *P. lateralis* there, and Europe has no native *Chamaecyparis*, the only host. The misleading, often repeated, suggestion that *P. lateralis* was introduced from France probably is due to misinterpretation of correspondence reproduced in the section on history of the disease. The correspondence clearly communicates that Washington nurseries were widely infested before 1922. The losses are reported from liner stock in the nurseries and from private plantings, not from the French stock. In fact, the disease progresses so rapidly that stock infested in France never would have reached America alive given the transportation available in the 1920's.

That *P. lateralis* arose in the Pacific Northwest outside the cedar region also seems unlikely unless there is an undiscovered host capable of sustaining the fungus. Such a discovery seems improbable because of research over many years and 60 years of observation of the cedar disease in conditions that exposed the fungus to hundreds of species of wild and cultivated plants. Prior to development of a horticultural industry around *Chamaecyparis*, there was no known host for the fungus outside the cedar region.

That *P. lateralis* might be harmlessly endemic within the range of Alaska-cedar, which is resistant but not immune (Torgeson and others 1954), has been suggested.<sup>26</sup> Possibly it behaves in the Alaska-cedar range like the *Phytophthora* species on wild plants in southern Oregon (Middleton and Baxter 1955). Roth (see footnote 26) suggested that when the artificially created forests of ornamental Port-Orford-cedar converged in southwestern British Columbia in the native range of Alaska-cedar, the harmless parasite on Alaska-cedar crossed onto the susceptible horticultural Port-Orford-cedar and spread aggressively southward. Although there are no reports of the fungus in native stands of Alaska-cedar, as for Asia and Europe, research on root diseases of native Alaska-cedar is limited; it is currently being expanded.

Schenck's (1907) observation, "In the sapling stage fungi seem to play havoc in the plantations, a fact which may explain the small range of the species," casts a final shadow of uncertainty over the origin of root rot. Schenck worked in both Germany and the United States, and the statement is too vague to tell which plantations he had in mind. So far as we know, there were no plantations at that time in southwestern Oregon. In 1907, diseases of the fine roots of trees were also relatively unknown to science. Hunt (see footnote 22) also is confident that Schenck was referring to something other than root rot.

<sup>26</sup>"*Phytophthora*, whence and whither," presented by L.F. Roth to Pacific Division, American Phytopathological Society, San Francisco, 1977.

**Biology of the fungus.**—*Phytophthora lateralis* has been studied extensively (Englander 1973; Trione 1957, 1959) in the laboratory but inadequately in the field. Infectious spores (zoospores) of *P. lateralis* form only in water when soils are saturated. Unlike spores of most fungi, which are airborne, zoospores swim and are splashed and washed about in surface water. Zoospores infect unsubsized root tips or, after winter storms, fallen green foliage. On the surface of infected tissue, soon after infection, the fungus produces hyphae that bear lemon-shaped spore sacs (sporangia), each of which releases 25-50 zoospores into the surrounding water.

Vegetative growth of the fungus is confined to the living host tissue. It does not occur independently in the soil (Ostrowsky and others 1977). Within the cambial region, the fungus seems to grow indefinitely until the entire root system is colonized, regardless of tree size. This may require a year or more in a large tree. The fungus lives vegetatively as long as the infected tree survives. Extension to new trees can occur through root grafts (Gordon 1974).

Within the host tissues, two kinds of thick-walled resting spores may be produced: asexually formed chlamydospores and sexual oospores. Both become incorporated into the organic fraction of the soil when the infected succulent tissues decompose. These spores can live for months, possibly years, and are the principal fungal forms moved in mud. They are also believed to be the primary means of survival through summer drought and other unfavorable periods. In saturated soil, both kinds germinate to produce single zoosporangia that return the fungus to the active infectious state.

**Development of the disease.**—As noted previously, active fungal growth occurs only in living tissues. While small succulent seedlings are killed in only a few days, large timber may survive several years after initial infection. Most of the vegetative development of this fungus is within the protective host tissues. In spite of a possible harsh soil environment, survival is assured as long as the infected tree is alive. Because infected trees always die and the fungus cannot grow outside the tree, effective spread of the fungus to neighboring trees is necessary to perpetuate the disease.

The structural root system of native Port-Orford-cedar consists of a fan of large roots that taper away from the root collar through the upper soil. Above these, in the humus layer, is a dense tangle of fine roots formed from the tips of "humus-striver" roots, which grow vertically from the structural roots (Gordon and Roth 1976). These fine roots produce many succulent tips at the soil surface that are readily accessible for infection by spores of *Phytophthora* being carried in the surface and soil water. The fine roots are probably also the site of most sporangial production. Because of this close association of host and fungus at the soil surface, *Phytophthora* root rot is particularly infectious for a fungus that lacks aerial transport.

Wounds are unnecessary for infection to occur. The swimming spores come to rest along the fine roots between the tip and point of first formation of bark. Fungal strands (hyphae) germinating from these spores penetrate directly into succulent tissues. Because fine roots of trees of all ages are alike, there appears to be little reason to expect resistance to change with tree age.



Vegetative growth of the fungus through inner bark and cambium of main roots probably continues throughout the year. By the time the root collar is invaded, the tree is so stressed that it dies from desiccation when exposed to drying conditions of spring and summer. The contribution to the disease cycle of vegetative growth within the tissues is not known, except that in the undisturbed forest, vegetative growth provides the means for relatively slow but unassisted spread uphill of fungi. In dense stands, fungal growth from tree to tree may occur through abundant root grafts (Gordon and Roth 1976). Knowledge of these tendencies enables the manager to prevent uphill spread by establishing appropriate tree spacing. Green foliage whipped to the ground by winter storms also may become infected by splashed zoospores. Fallen dead foliage probably is not infected, particularly in competition with saprophytic fungi (Ostrofsky and others 1977).

Chlamydospores form quickly in parasitized fine roots and freshly fallen branchlets. These enable dormancy and longevity of the fungus. Decaying, spore-bearing tissue becomes part of the organic fraction of the soil from which the fungus, in the absence of infected living tissue, can be most readily, but not easily, recovered (Ostrofsky and others 1977). How old this material can be and still yield living fungus (be infectious) is not known, but it is certainly several months and possibly a few years.

Fate of mycelia that invade the structural root system and girdle the tree at the root collar is unknown. They may produce chlamydospores, sporulate at the surface after penetrating the thick bark, extend to the far side of the root system to sporulate there on fine roots, or sporulate again on the now dead roots at the point of initial attack. These matters can, in part, determine how long a site remains infested. Forest managers require an estimate of this longevity. Until the appropriate studies are completed, we suggest a minimum of 3 years.

Unassisted spread of root rot outside the host is limited to periods when soils are saturated. Because this fungus sporulates actively at cool temperatures (Trione 1974), spread by splashing rain and by washing occurs throughout the 5-month wet season after soils become saturated.

This fungus is confronted with real obstacles to wide natural dispersal, especially where topography is steep. Flowing water containing spores is quickly channeled into narrow waterways, leaving most of the terrain beyond reach of the spores. Vegetative extension through the stand is stopped by gaps in the cedar stand. Only with some agent to carry it can the disease be epidemic on wild land.

Wide distribution of cedar root rot resulted from shipment of nursery stock in infested soil. In the cedar region, local distribution and intensification resulted from earth movement during construction and road maintenance. Runoff from contaminated areas resulted in general infestation of water courses, lakes, and sloughs. Epidemic conditions have been most severe and most visible where human activity has been greatest. Damage is presently less visible and in some places less intense because surviving trees are on less accessible sites. On accessible sites with good soils, much mortality is screened from view by replacement vegetation.

Some slowing of the spread of the disease has accompanied leveling off of construction in the region, and the disease is forced to depend on less efficient, natural means of spread.

The disease continues to appear occasionally in seepage areas in quite remote places. This probably results from being carried by some unidentified animal or from some unknown human activity.

**The response of disease to environment.**—Root rot appears not to be influenced by soil type. It attacks equally cedars on soils derived from sedimentary rocks near the coast, on ultramafic soils in the mountains, and on deep, sandy loams in the northern Willamette Valley.

Active parasitism requires favorable temperatures when soils are saturated. Unlike many root-infecting *Phytophthora* species, *P. lateralis* thrives at the low soil temperatures that prevail during wet weather in the maritime Pacific Northwest. It is not inhibited by milder temperatures.

Temperature indirectly affects the disease by influencing drying of soil and the duration of dry periods that debilitate the fungus. Climatic differences within the cedar region influence the amount of disease: The rate of disease development among trees generally is slower in the warmer and drier parts of the region. This effect is confounded, however, by lower density of cedar in the drier country.

Soil moisture is by far the greatest environmental influence on root rot; the longer the wet season and periods of soil saturation, the more abundant the disease.

**Characteristics of epidemics.**—Understanding how epidemics work can aid management for disease control and will help the manager develop special procedures to meet particular disease situations.

All epidemics share the three essential components: (1) large populations of susceptible hosts, (2) abundant inoculum, and (3) favorable environment. Cedar root rot also requires some means of transmitting the inoculum. If all components are present in optimum amounts and are ideally timed, the epidemic will be severe, and trees will become infected at a high rate. (These conditions were approximated as cedar root rot developed along the coast of Coos and Curry counties.) Any reduction of an individual component will reduce the probability of infection. Wide spacing of the cedars, reduction of inoculum, carrying out forest management operations in dry weather, and reduction of carriers of spores can be used individually or jointly by the manager to dampen an epidemic.

#### Genetic Resistance to *Phytophthora lateralis*

Although there has been no general screening of seedlings for resistance to *P. lateralis*, thousands of cuttings have been tested from several hundred trees that survived among dead associates. All tested cuttings died. This suggests either that the parent trees escaped infection and there was no resistance to root rot or that inoculation during testing was too severe. Extended survival of some trees may be an inherited trait that can be genetically strengthened to provide a usable degree of field resistance. This hypothesis should be tested.



## Chapter 8: Management Considerations

Appropriate future management of Port-Orford-cedar will differ substantially from that of other species. It must include consideration of (1) the market peculiarities, which for cedar differ from those of other commercial timbers; (2) cedar's potential uses, which are not reflected in the current export-dominated market; and (3) the details of the major disease, which limits the commercial range and complicates production.

### History of Use

The primary uses and markets for Port-Orford-cedar changed drastically within its first century of use as a commercial timber. Aboriginal Americans and European settlers, who entered the range of cedar in the early 1850's, used it for a variety of purposes, including housing, furniture, and fuel (Beckham 1973a, Beckham 1973b, Peterson and Powers 1952). A mechanical sawmill produced lumber for coastal Oregon gold mines (Oregon Historical Records Survey 1942), and a second mill, at Port Orford, sawed the first lumber shipped to San Francisco in 1853 (Knapp 1981). By 1857, cedar lumber was the highest priced and most useful wood sold in San Francisco (Kellogg 1857, also see appendix). Cutting for the California market expanded to mills along the Coquille River and around Coos Bay; by the late 1860's the latter area produced most of the cedar lumber cut (Beckham 1973b). Early consumption of Port-Orford-cedar wood was apparently limited to the Pacific coast: two prominent dendrologists from the eastern United States made a special side trip to Coos Bay to see whether cedar lumber used in Portland, OR, came from the tree they knew as the ornamental Lawson's cypress (Sargent 1881). The species had become a popular garden tree in Europe after British plant collectors obtained seed from interior California in 1854 (Gordon 1875, Murray 1855a, Murray 1855b).

Early uses of the wood were many and varied (fig. 29). Production increased substantially in the 1880's, after 1907, and during World War I when larger mills were built (American Lumberman 1911, Douthit 1981). The boom in cedar production during most of the 1920's and 1930's was based on its use in automobile storage batteries (1 billion wooden battery separators were produced at Coos Bay in 1936 [Lamb 1938]), export to Japan and Europe (50 percent of production from Coos and Curry Counties in 1923 to 1935 was exported [Oregon Historical Records Survey 1942]), as well as traditional domestic uses. These specialized uses kept cedar mills running during periods of severe depression in the rest of the timber industry (Douthit 1981).

Following World War II, substitutes were developed for two major cedar products, venetian blind slats and battery separators, and the price and use of cedar had plummeted by the early 1950's (Stillinger 1953). The export trade with Japan began again, however, and soon dominated the cedar market. In 1981, the primary domestic cedar product was produced by three arrowshaft mills (Associated Press 1981), with one small mill each producing custom-sawn lumber for export and bleacher seating.

### Partial List of Uses for Port Orford Cedar

Airplanes	Frames, picture	Rolls
Arrowshafts	Furniture	Sash
Baskets	Gauges, gasoline	Screens
Beehives	Greenhouses	Separators, battery
Blinds, venetian	Grills	Shells, racing
<b>Boards, boat</b>	Handles, paint	Shelves
Boards, drain	Hangers, garment	Ships
Boats	Icing Platforms	Shoes, sash
Bowls	Instruments, musical	Siding, house
Brushes	Instruments, scientific	Sills
Broom Handles	Keys, organ	Silos
Cabinets	Launches	Stools
Casings, house	Lawn Furniture	Strips, sash
Chests, clothes	Linings, closet	Tables, card
Closets, linen	Mantels	Tables, novelty
Crates	Matches	Tanks, water
Crating	Mine Timbers	Toys
Culverts	Mouldings	Trim, house
Decking, bridge	Novelties	Tubs
Decking, ship	Organs, pipe	Tunnel Timbers
Doors, house	Paper Mill Machinery	Turnings
Doors, screen	Paving Blocks	Vats
Dowels	Pergolas	Vehicle Parts
Drawers	Piling	Veneers
Finish, house	Planking, boat	Wardrobes
Finish, hospitals	Plywood	Windmills
Fixtures	Poles, curtain	Woodenware
Flooring blocks	Poles, telephone	Yachts
Frames, boat	Posts, guard	Yardsticks
Frames, mirror	Presses, filter	

Figure 29.—A partial list of uses for Port-Orford-cedar given in an advertising and information bulletin (Port Orford Cedar Products Co. 1929).

### Use of the Exported Wood

The Japanese buy Port-Orford-cedar lumber as a partial substitute for their native hinoki, which has traditional uses in construction of houses and temples but is in very limited supply. "Flawless hinoki is held in religious veneration by the Japanese" (Lamb 1929, p. 39). The Japanese market has taken essentially all the large green timber produced in recent years.

Under present conditions of nearly exclusive export and high values, logs are separated into two groups, those less than 30 cm diameter and those larger. The units with logs of mixed quality and size may be sold either at auction or to a single agent. When large quantities of cedar are included in a federal timber sale, agents of one of several large Japanese trading companies may purchase stumpage on bid after detailed examination of the individual cedar trees and consultation with their client. Trees are felled with care, in some cases using cables to control the fall.

## Prices of Port-Orford-Cedar

Logs are graded by the Japanese into the five quality ratings: large logs with 90 percent, 75 percent, 50 percent and less surface clear, and utility (logs less than 30 cm and those with little clear surface). Within the higher quality classes are further subdivisions by size. Within any one quality-diameter grouping, however, price can vary considerably based on wood characteristics. Second-growth wood is used only when concealed as floor joists or framing. Eight to ten rings per inch has been considered coarse-grained.

Port-Orford-cedar wood has commanded a premium price throughout most of its commercial history. Its early price in San Francisco was at least twice that of Douglas-fir and redwood (Cox 1974, Appendix I; Dodge 1898). Stumpage before the Great Depression rose to \$18/MBF (thousand board feet) (Oregon Historical Records Survey 1942). Following World War II, when domestic use declined and before export to Japan was reinitiated, cedar stumpage fell to \$2-4/MBF. Cedars were often left standing after harvest cutting and logs were cut into ungraded dimension stock. By the early 1960's, prices for export were higher than for Douglas-fir and rising (fig. 30). In 1981, logs exported from the Powers Ranger District, OR, sold for an average of \$2,166/MBF.

A high price for Port-Orford-cedar requires clear, fine-grained old-growth of large diameter (see Wood Properties, Chapter 5). Port-Orford-cedar is high on a list of replacements for the Japanese native hinoki: Taiwanese *Chamaecyparis* is the first alternate, and Port-Orford-cedar is second, followed by Alaska-cedar, Sitka spruce, and noble fir (*Abies procera* Rehd.) The demand depends on the price and quality relative to the several alternative woods available. During the late 1960's, prices of Port-Orford-cedar in Japan rose more rapidly than for any other wood except hinoki and exceeded those of other American imports (table 63).

Log prices vary considerably with size and quality (table 63). Before a 1981 slump in the market, utility-grade logs (defective or less than 30 cm diameter) brought up to \$300-400/MBF in the United States, and the highest quality large logs brought \$2,000 to \$6,000. Decks of mixed-quality logs 30 cm and larger have sold for \$500 to \$1,800/MBF in recent years. Much young cedar from farm woodlands is open-grown, has characteristically poor form, coarse grain, and many knots. It is derogatorily termed "farmer's cedar" and sells as "utility grade" at a flat price when there is a market. During the 1981 slump in the market, second-growth utility-grade logs were selling on the domestic market for as low as \$135/MBF.

Bids for stumpage varied from \$1,000 to \$5,000/MBF in the Siskiyou National Forest in 1980-81. The high bids were based on expectation of yield exceeding the official estimates, from speculation on future price rises, and in some cases on ignorance of the realities of the market. In other cases, the cedar may be the only biddable item in a mixed-species sale, or the bidder may bid high on a small cedar volume to get the Douglas-fir. The presence of cedar occasionally inflates the price bid for Douglas-fir. To discourage playing games with the bidding, some management units have excluded the cedar from the bidding, and others have tried to concentrate the cedar into sales separate from those sales including primarily other species. Other managers allow bidding only on species that comprise more than a minimum percentage of the sale.





Figure 30.—Log prices of Port-Orford-cedar exported from Oregon Customs District, 1961-81, in dollars per thousand board feet Scribner scale (Ruderman 1979, 1982).

Table 63—Wholesale prices (dollars per thousand board feet) of Port-Orford-cedar logs, Japan, 1965-70, compared to other imported species and small hinoki<sup>1/</sup> logs by species, Japanese log grade, and log diameter

(In dollars)

Year	Hinoki, 1/ all grades, 14-23 cm	Port-Orford-cedar			Sitka spruce, No. 1, 76+ cm	Noble fir, No. 2, 46+ cm	Douglas- fir, No. 3, 30+ cm	Western hemlock, No. 3, 30+ cm
		No. 3, 30+ cm	No. 2, 46+ cm	No. 1, 61+ cm				
1965	214	205	336	522	252	208	153	152
1966	266	224	433	672	272	239	158	153
1967	354	306	651	974	312	294	170	162
1968	391	323	622	917	350	318	177	171
1969	446	327	626	975	388	249	188	177
1970 <sup>2/</sup>	455	328	632	1020	375	259	197	178

<sup>1/</sup> *Chamaecyparis obtusa*.

<sup>2/</sup> First quarter only.

Source: Austin 1970.

Certain types of salvage are reserved for use as short bolts and are intended for arrowshafts, but recently some short bolts have been exported. Prices for arrow bolts were \$6-47 per cord in the field and \$90-150 at the mill in 1981; the same type of material exported during a strong market in about 1980 brought \$300-400.

**Size of harvest.**—Total volumes cut are not available for the early years. Forty million board feet were cut in Oregon in 1916 (Henley 1973) and about 50 million in 1920 (Peavy 1922). The cut rapidly increased during the 1920's in Oregon; the 1925 cut was 59 percent lumber, the rest veneer stock and squared logs (Dion 1938). Oregon log production (fig. 31) dropped drastically during the early depression years, recovered through World War II, and then declined again. The volumes given as "log scale" in figure 31 are below those quoted by Dion (1938) for the 1920's. Henley (1973) cites the 1940-43 cut as averaging 62 million board feet for lumber and 29 million for veneer and other uses (well above amounts shown in fig. 31). In 1960, domestic consumption was less than 1.7 million board feet; it was probably below 0.5 million by the 1970's (Henley 1973).

The percentage of Port-Orford-cedar in the timber harvest has exceeded its proportion of the timber supply, and concern about overcutting was expressed even by earlier writers. In Coos and Curry Counties, cedars accounted for 23 percent of saw-log production in 1925-29; 14 percent in 1930-40; and 11 percent in 1940-44. In contrast, it accounted for only 3.2 percent of the sawtimber supply (Marquis 1947); the comparable estimate was 14 percent in 1902 (Gannett 1902).

The volume exported in log form (most of that harvested in recent years) has declined since 1961 (fig. 31). The relative importance of Port-Orford-cedar in the export market has also declined, although cedar's high price has kept it as a higher proportion of export value than of volume (fig. 32). During most years between 1961 and 1982, over 99 percent of exported Port-Orford-cedar went to Japan (Ruderman 1979, 1983).

The Powers Ranger District, Siskiyou National Forest, OR, is the major producer of cedar. In the early 1980's, 5 to 7 million board feet of cedar was cut there annually (10 to 14 percent of the total harvest from the district); in addition, 0.3 million board feet of arrow stock was removed and a like amount of other wood salvaged per year.

**Volume of growing stock.**—The most recent estimates of total remaining growing stock are 4.6 million m<sup>3</sup> for Oregon (52 percent on Federal lands) and 1.2 million m<sup>3</sup> for California (Ohmann 1982; footnote 27). Half the growing stock volume is in Coos County, OR. Table 64 gives the available county-by-county estimates. Volume is concentrated in larger trees, especially in California (table 65). Growing stock in Oregon was 7.5 million m<sup>3</sup> in 1948 (Moravets 1951). Board foot volume in Oregon at the turn of the century was 2,652 million, 2 percent of it west of the Cascade Range; three quarters of the cedar was in Coos County (Gannett 1902). More recent board foot estimates (Scribner rule) have been: 1932-33—1,397 million; 1948—1,688 million; and 1963—933 million (Henley 1973). The present board foot volume in Oregon is probably about 450 million (Scribner rule), compared to the 240 million estimated for California (Kliejunas and Adams 1980).

<sup>27</sup>Personal communication, 1982, Janet Ohmann, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.



Figure 31.—Log production of Port-Orford-cedar in Oregon, 1925-51, exports to Japan, 1927-38, and log exports from Oregon and California, 1961-82. Values for 1949-51 are the estimated maximum. Data are given in million board feet, Scribner. (Data are from: 1925-51: Stillinger (1953); 1961-82: Ruderman (1979, 1983); exports, 1927-38: Elchibegoff (1949).)

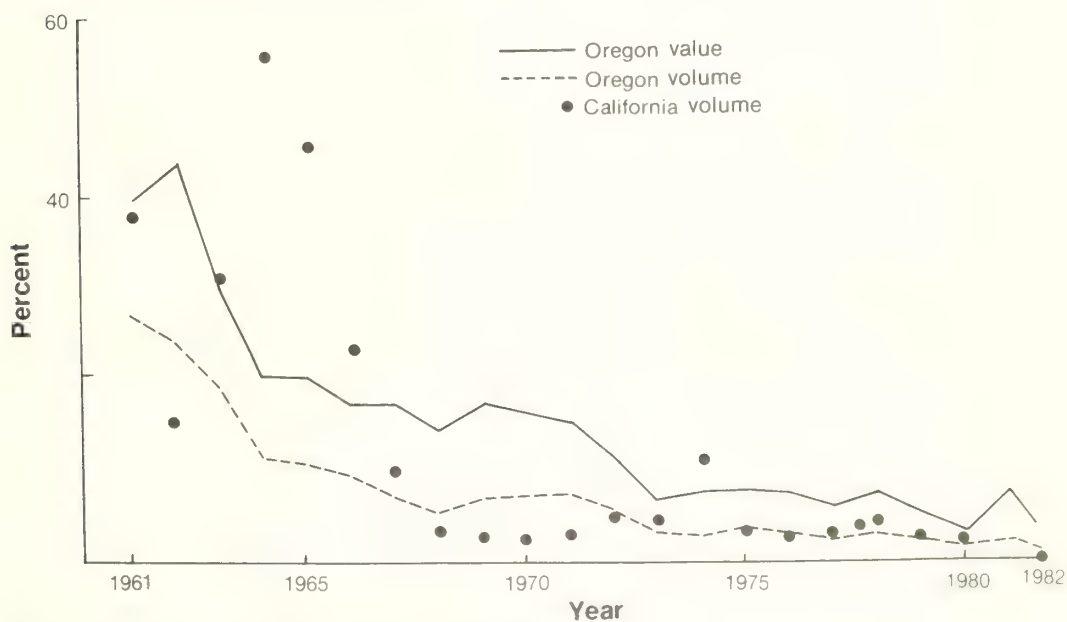


Figure 32.—Port-Orford-cedar log exports as a percentage of total volume and value of softwood log exports from Oregon and as a percentage of volume exported from California, 1961-82 (from Ruderman 1979, 1983).



**Table 64—Forest survey information for volume and growth of Port-Orford-cedar, by county**

County	Area in forest type	Volume of growing stock	Volume of sawtimber			Net annual growth	
			Scribner	International (1/4")	Cubic	Scribner	International (1/4")
	thousand ha	thousand m <sup>3</sup>	- - - million board feet - - -			- - - thousand board feet - - -	
Oregon:							
Coos	17.8	2,915	296	441	105.8	5,832	13,436
Curry 1/	7.7	255	12	23	7.3	-189	760
Josephine	1.6	198	25	29	2.3	ND	250
Douglas	4.1	ND	ND	ND	ND	ND	ND
California: 2/							
Humboldt	ND	28	ND	ND	ND	ND	ND
Shasta, Trinity, and Siskiyou	2.4	538	97	105	5.7	1,100	1,100

ND = no data available.

1/ Volume and growth on National Forest land are not included.

2/ No data for Del Norte County.

Source: Bolsinger (1976) for 1970 in Shasta, Trinity, and Siskiyou Counties, CA; for Oregon and Humboldt County, CA, for 1980, unpublished data on file, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

**Table 65—Percentage of Port-Orford-cedar growing stock, Oregon and California, by diameter class**

(In percent)

State	Lower limit of diameter class (centimeters)										
	12.7	18.0	22.9	27.9	33.0	38.1	43.2	48.3	53.3	73.7	99.1
Oregon	12	11	2	6	9	5	10	2	17	12	12
California 1/	t	t	--	10	t	5	10	t	14	25	15

-- = none; t = less than 3 percent.

1/ Excluding Del Norte County.

Source: From USDA Forest Service, unpublished data on file, Pacific Northwest Forest and Range Experiment Station, Portland, OR; Bolsinger 1976.

Growing stock volumes (table 64) were about 1 percent of the total softwood volume in the Oregon and California counties involved (Bolsinger 1976, Hazard and Metcalf 1964). Annual exports from Oregon from 1977 to 1980 averaged about 2.5 times the estimated net annual growth of sawtimber, and about 4 percent of Oregon's estimated present volume of Port-Orford-cedar sawtimber, a figure similar to Henley's (1973).

Small, unevenly distributed timber volumes, as those for Port-Orford-cedar, are subject to large errors of estimation (Bolsinger 1976), and estimates from different eras may differ because of changes in estimation procedures.

In Oregon, the 31 000 ha of Port-Orford-cedar forest type are owned by the forest industry (38 percent), the Federal government (30 percent), other private parties (20 percent), and other public agencies (12 percent) (Gedney 1982).

## **roduction of lorists' Greens**

Port-Orford-cedar branches are collected in the natural range for use by florists. One company in Coos Bay ships about 127 000 kg annually, with the major proportion in autumn. Collectors received \$0.30 per 0.9-kg bunch in 1983; retail florists in western Oregon paid about \$1.10/kg.

Collection is often by permit only, and collections per tree are supposed to be limited. Given little regulation, sometimes collectors strip most of the crown, which reduces cedar's relatively slow growth rate even further.

## **ast and Current lanagement Practices**

Management of Port-Orford-cedar in the native range, other than by harvesting, has been limited. In 1910, defective trees were being left as seed sources and seedlings were grown in a Coos County nursery (American Lumberman 1911), but no information about early plantations is available. Limited planting in the northern Siskiyou National Forest in the late 1950's and early 1960's was discontinued when root rot caused nurseries to stop producing stock. Currently, with a fuller understanding of the root rot problem, the Siskiyou National Forest is planting cedar to supplement natural seedling establishment.

The earlier planting was of 2-0 stock at 2.4-m spacing in alternate rows with Douglas-fir; recently, container stock 20-30 cm tall was planted at 6-8-m spacing within and in addition to the regular Douglas-fir planting. Farther north in the Coquille River drainage, 25,000-50,000 cedars have been planted annually since the mid-1970's on industry land. Sufficient container stock, 30 cm tall, has been interplanted with Douglas-fir (fir at 2.7-m spacing) to form a third of the stand. Industry plantings have been confined to local areas without root rot, where no seed source was available. Experimental plantings for control of gorse were relatively successful (Hermann and Newton 1968), but later were destroyed by root rot.

In many management units, no guidelines exist for the management of young cedar stands. The necessity to thin precommercially has not yet occurred in some areas. Events are now forcing decisions about management to be made in most of the cedar's commercial range, however, by default if not on purpose.

In the past few years, precommercial thinning in stands with cedar has become more common, and it will continue to increase. Some selection for and against Port-Orford-cedar has occurred. After 1962, cedar was specifically removed in some Forest Service thinnings; cedar was left as a crop tree only where Douglas-fir or hemlock were not available. Where the thinning criterion is size, cedar trees seldom survive. In some National Forest districts, minor species (including cedar) are consciously favored to increase stand diversity, although they represent less than 1 percent of the trees left. Recently in the Powers Ranger District, OR, the Forest Service has tested the practice of thinning cedar independently of the primary crop species. All cedars are removed in a 15-m band along streams and below roads; then, farther from potential sources of infection, they are left at 8-m spacings, so long as they are more than 1.2 m from a taller primary crop tree (usually Douglas-fir). The main thinning regime for Douglas-fir is at 3- to 5-m spacing. The wide spacing of cedar is designed to eliminate root overlap and reduce tree-to-tree spread of root rot. Precommercial thinning is done at stand ages of 10 to 15 years. Twenty years may be appropriate on poorer soils.

Few natural stands of cedar have been commercially thinned. In coastal Coos County, some thinning to a maximum 6-m spacing has been done. Thinning in dense stands increases the danger of windthrow and almost ensures introduction of root rot. No stands have been thinned during their development, so it is not known to what degree stocking control is possible.

Most coastal stands are cut at about 60 years when cedar is only of marginally commercial size, although some concentrations of cedar will be cut on longer rotations. Near the coast, danger of windthrow plus regeneration requirements of the desired species have precluded use of any harvest methods besides clearcutting.

Experience in Great Britain indicates that Port-Orford-cedar slowly fills gaps left by thinning; its shade tolerance and narrow crown suggest that stands should be left denser than those of most other conifers (Macdonald and others 1957). Natural pruning in dense stands is very slow (Macdonald and others 1957, Schenck 1907).

Early experimental plantations in the Pacific Northwest have been described only briefly (Duffield 1956, Hayes 1958, James 1958, Krygier 1958, Ruth 1957). Plantations established in southwestern Washington in the 1930's were damaged by a cold wave in 1955 (Duffield 1956); all that remain of some extensive ones in Cowlitz County are scattered understory trees.<sup>28</sup>

One plantation near Mapleton, Lane County, OR, was planted on an old pasture in 1942 (USDA Forest Service, no date). Stocking at age 37, after pole removal at about 30 years, was 1265 trees per ha (mean diameter 28 cm, basal area 63 m<sup>2</sup>/ha). It was recently invaded by root rot and destroyed by wind in 1981.

Although the species will grow reasonably well in sufficiently moist habitats in many countries, its future in forestry outside North America is perceived to be quite limited. Forestry plantations have been made in several areas of Europe (Boullard 1974, Hamilton and Christie 1971, Hayes 1958, Holmsgaard and Bang 1977, Macdonald and others 1957, Schwappach 1911, Streets 1962), as well as in Australia, Ceylon, Kenya, Mauritius, New Zealand, and South Africa (Streets 1962). In no case, however, does Port-Orford-cedar seem likely to play a major role in forestry; other conifers are more productive on the sites where the cedar grows best<sup>29</sup> (Boullard 1974, Macdonald and others 1957, Streets 1962).

#### **A Look Ahead: Management in the Presence of Root Rot**

The cedar root rot epidemic appears so threatening for most of the Port-Orford-cedar range that interest has been expressed in nominating the tree for listing as an endangered species; however, the aggressive reproduction of cedar and natural restrictions on the fungus indicate that the survival of cedar as a species is not threatened. Survival as a commercial timber will be limited, though, unless successful management is achieved. Over the next 30 years, old-growth cedar probably will continue to be harvested, and to die from root rot at a declining rate paralleling exhaustion of the resource.

<sup>28</sup>Personal communication, 1981, F. Nicoll, International Paper Company, Portland, Oregon.

<sup>29</sup>Personal communication, 1982, B.P. Glass, New Zealand Forest Service, Rotorua, New Zealand.



The only significant young growth (age 30 or older) available after the old growth is gone is along the coast. It is heavily depleted by development, is widely damaged by root rot, and (except for Coos County Forest) seems unlikely to be managed to reduce the disease. This timber will probably not outlast the old growth in the mountains. Realistically, it will be at least 100 years before the species can again be a major contributor to the economy of the region and that will come only with effective timber and disease management.

In this situation, undertaking special management may seem useless. Despite the problems, however, a well-planned, well-executed effort can be justified by the following: (1) The high per unit value of exported cedar generates a major cash return to forest land owners and, through payments in lieu of taxes on public land, a valuable source of revenue for local governments. (2) The highest cash return from the mountainous forest land in the northern part of the cedar range is realized from timber production by stands in which cedar is mixed with Douglas-fir, and in which the cedar is harvested at its appropriate rotation age. Cedar appears to compete little with the Douglas-fir, so the extra value cedar adds to the harvest is a bonus. (3) Cedar is the best growing species as well as the most valuable on many of the serpentine mountain sites common in the region. On some sites it is the only species that can reach commercial quality. (4) Much of the limited cedar forest is biologically distinctive and, in the southern part of the range, is ecologically and floristically unique, deserving special management for its perpetuation on these grounds alone.

By working cooperatively with natural constraints on the disease, sustained, informed disease management can succeed in producing healthy crops on much of the land in spite of the acknowledged obstacles.

These are several possible objectives for managing Port-Orford-cedar.

1. To allow cedar trees to escape the root rot disease. Success in this objective is necessary to achieve the other objectives throughout most of the commercial range. That situation may eventually extend throughout the botanical range.
2. To retain the species and its genetic diversity. The species is threatened on better sites by routine management for other species, which removes surviving cedars before they reach reproductive age. Loss of the genetic types on good sites would be tragic. These populations have the most potential for being used in case more effective root rot control measures develop or for being planted outside the range.
3. To retain biotic diversity, as mandated in the National Forest Practices Act, and aesthetic quality. Port-Orford-cedar is a beautiful tree; it is the largest tree on some ultramafic sites, and it is the most shade-tolerant conifer in much of its range.
4. To retain the apparent ameliorative effects of cedar on soil properties. Cedar litter is less acidic and higher in calcium than that of associated conifers. Foresters have suggested that the capacity to grow other trees on some ultramafic sites may result from the influence of cedar on the soil.

## **Objectives of Cedar Management**

5. To produce additional revenue from forests managed on normal rotations for other species. Cedar may produce small saw logs on good sites in the course of a rotation; some foresters believe that the presence of cedar will not adversely affect the yield of the primary species.

6. To produce cedar as a primary product.

6a. Present market conditions require large, slowly grown, and therefore old trees. Areas dedicated primarily to production of high-value cedar, or areas managed on old-growth rotations for other reasons, are required. On poor sites where cedar is the primary commercial species, production of large, old trees may be the only commercial timber use possible. In all cases, the sites must be the least susceptible to introduction of the fungus, and the landholder must be dedicated to cedar production. A small market for an intermittent supply must be available.

6b. If the market for small saw logs develops, or if future markets develop in which mechanical, not aesthetic, properties of the wood are of primary value, shorter rotations to produce rapidly grown but smaller trees would be feasible.

7. To diversify the economy of the Port-Orford-cedar region. Commercial production of cedar brings economic diversity and the likelihood that a cedar market would allow for continued forest industrial activity in times of depression of the overall market, as has occurred in the past. Development of locally manufactured products would increase the economic benefit. Cedar production also supports minor industries, such as collection of florists' greens and production of arrowshafts.

#### **General Guidelines for Future Management**

Port-Orford-cedar can be successfully managed in spite of root rot. To minimize damage, management should strive to:

1. Minimize spread of inoculum (infested earth, mud, or gravel) during construction and maintenance of forest access roads.

2. Conduct forest operations and forest use in a sanitary way, particularly avoiding contamination caused by moving uncleaned equipment from infested to uninfested sites. Site contamination is a particular danger when timber killed by disease is being salvaged.

3. Concentrate cedar production as high above and as far from infection sources as possible without unreasonably limiting the amount of growing stock. Concentrations of cedar should be on high ground and well away from roads. The ratio of cedar to other species should decrease close to roads and on more gentle slopes.

Chances of successful management will be enhanced by two severe limitations on the fungus: (1) There is no secondary host for the root rot. (2) Natural spread of the fungus is by spores in surface water which, in the rough topography of the cedar region, mostly flows into narrow, natural waterways away from the growing stock.

Observations of Port-Orford-cedar throughout its range by many people for nearly a century indicate consensus on at least three aspects of productivity: (1) On good sites, at least during midlife, Port-Orford-cedar grows more slowly than most associated conifers. It is therefore not completely compatible with rotation ages desired for management of the principal species on these sites. (2) On extensive ultramafic sites, Port-Orford-cedar outperforms other species and may be the only species with future commercial potential that can be grown on such sites. Alternative species such as sugar and western white pines are plagued equally by disease. (3) On good sites in mixed stands, cedar is smaller than Douglas-fir and appears to be noncompetitive with it. Cedar can therefore be grown at little added cost and can be harvested at the appropriate time as a bonus to normal Douglas-fir yield.

Recent ecological work (summarized in Chapters 3, 4, and 6) has more specifically defined the forest types in which the cedar grows, and demonstrated differences in cedar growth rates associated with forest type. This work has also confirmed that Port-Orford-cedar apparently requires abundant soil moisture throughout the growing season, but appears to be less sensitive to cold, wet soils, to a wide range of air temperatures, and to soils of low or poorly balanced nutrient concentrations than are the major associated conifers. It has been demonstrated that Port-Orford-cedar affects the properties of surface soils differently from conifers associated with it.

Little information is available (see Chapter 6) on volume growth and yield, particularly as these relate to levels of growing stock, stand composition and site quality.

Because silvicultural data are so limited and the root rot threat is so pressing, it seems reasonable that management guidelines for sustained cedar production should emphasize reducing the impact of disease.

**Strategy for control.**—There are no available means for direct or chemical control of Port-Orford-cedar root rot, nor does cedar have a proven usable level of genetic resistance to *Phytophthora*. Port-Orford-cedar is so susceptible to *P. lateralis* that the tree cannot be grown in the presence of the fungus. The only strategy currently available for control is escape. The level of success depends mostly on the manager's ability to limit disease spread. Spread results largely from human activity, much of which is subject to regulation; however, spread by means of hooves of animals greatly complicates the task of growing trees that will escape the disease.

Management based on escape from disease is a long-term undertaking. Some young cedar may be cut, for fiber or other domestic use, concurrently with harvest of rotation-aged Douglas-fir sawtimber. Cedar appears unlikely, though, to attain high value for the export market in less than 200 years (at a minimum, two rotations of Douglas-fir). The fine grain and large size needed for export value require slow growth for long periods.

## Management to Minimize Effects of Root Rot



Root rot has become so conspicuous in the commercial forest that the thought of trees escaping infection today, much less for 200 years, may appear impossible. Several considerations suggest, however, that protecting trees by management is feasible: (1) the disease is sharply restricted by natural features of host, fungus, and habitat; (2) discontinuous distribution of the cedar precludes vegetative growth of the fungus uphill; (3) aerially transmitted spores are lacking; and (4) the spores are spread by water, which prevents the disease from moving rapidly up the slopes.

The manager's goal becomes one of growing cedar on sites that are unlikely to be reached by the root rot fungus. This requires minimizing activity by potential carriers of spores and moderating impact where activity is unavoidable. This is particularly important during conversion of the forest from an unmanaged to a managed state, which requires construction and disturbance that easily spreads the disease. The forest will stabilize upon final conversion and the rate of disease development will decline.

**Suppression tactics involving individual components of the epidemic.—**

Specific suppression tactics are applicable to individual components of the cedar root rot epidemic (host, pathogen, and environment), and to physical and functional factors influencing the components. These various elements are inextricably interwoven and difficult to discuss in isolation.

*Achieving safe siting and spacing.*—Large populations of susceptible cedars, vulnerably situated, are the foundation of the cedar root rot epidemic. *Phytophthora lateralis* probably never would have emerged in epidemic form, if at all, without mass production of ornamental *Chamaecyparis* in northwestern Oregon and Washington and its widespread planting. Logically, whether in the native cedar range or elsewhere, the reverse procedure of reducing the cedar population should suppress the epidemic. The disease, of course, is already doing this, but this unplanned loss in the forest defeats the silvicultural objective of sustained high volume production of cedar. Accordingly, we are caught in a paradox in which the very trees we need are the heart of the problem.

In a direct way, a large population enhances an epidemic only in that large numbers of trees increase the proximity of individuals, so that probabilities of exposure to contagion are raised. A large number of infected trees provides a massive source of spores that indirectly may be as important to the epidemic as is the death of those trees. This is particularly true of trees too small for commercial use.

Both cedar and fungus are favored by moist habitats, so the cedar population is concentrated in the sites most vulnerable to infection. Because most of these sites are unlikely to escape contamination, the only alternative now available to the manager is to remove these cedars and replace them, where possible, with immune species (any other conifer suited to the particular site) that will suppress Port-Orford-cedar regeneration. Cedar production must be shifted onto the less vulnerable, convex, uphill slopes beyond the influence of drainages and roads. On fertile, convex slopes in the northern part of the range, cedar establishment and growth are excellent, but protection from suppression by Douglas-fir will be necessary where cedar production is shifted to these sites.

Where water is the only probable means of disease spread, the shift to higher ground need be no more than 15 m, and hillside stocking on safer sites can be increased to as high as 25 percent. Intervention by elk or other carriers is, unfortunately, quite possible at such locations; distances from drainages and between trees must be increased as game densities and livestock increase.

A shift of cedar production away from the wet areas is not an available alternative in the southern, drier, and inland parts of the range. There, a rigorous program is needed to protect existing stands. Such a program can be highly effective because stands are already widely dispersed and the prevailing general environment discourages movement of the fungus.

*Limiting inoculum supply.*—Inoculum consists of waterborne zoospores and of resting spores formed in the forest litter and the organic fraction of the soil under diseased trees. At sites of high activity by potential carriers, resting spores incorporated into mud constitute the principal contagion. This mud, moved on hooves of animals and by vehicles and machines, accounts for broad distribution of root rot within the forest. Although swimming spores are widely produced from this contagious slurry and from living infected rootlets, and although they are the only infective agents, they become narrowly channeled by flowing water; their function in epidemic spread of root rot is limited except where water accumulates. The larger the area of infected trees on sites where water accumulates, the greater are the probabilities that carriers will enter the area, pick up, and spread the inoculum. Flood waters causing erosion are believed to move the long-lived resting spores so that alluvial gravels become contaminated and infectious. Quarry rock rather than river gravel should be used on roads.

The main objective of management, as it relates to inoculum, must be to limit or reduce the number, size, and accessibility of sites where transmitters can pick up the fungal spores.

Production of new sources of contamination can be reduced by prelogging cedar in vulnerable situations and using cleaned equipment. Operations must be based on overall long-term management objectives and the present root rot distribution. Agencies will need to classify all their cedar sites according to vulnerability to infection. Attention must be given both to position of the trees, including proximity to existing mortality, and to location and scheduling of work planned for each locality. The most exposed patches should be expeditiously and completely removed. Work should proceed to progressively less vulnerable stands. Cedar on convex slopes or above roads, or that are otherwise protected, should be retained for later harvest, even though heavy demand for Douglas-fir will generate considerable pressure to harvest these mixed stands prematurely.

This preventive harvest plan cannot be carried out using "business as usual" methods. Many units will be small and difficult to log; logging them will demand care and thoroughness. The units will include substantial cedar volume, however, and in most cases will be of sufficient value to justify considerable cost. Every small tree must be logged or killed. To limit cedar regeneration, logging should cause minimal disturbance of the forest floor, and alternative immune species (western hemlock, western redcedar, true firs, Douglas-fir, or hardwoods) should be protected and regenerated on the site at the highest possible densities. Prescribed fire might be used to remove unwanted cedar saplings. On some serpentine sites, protective vegetative cover may have to be entirely brush species, forbs, and grasses. To avoid introducing the fungus, all work should be done in the driest part of summer with machinery that has been thoroughly scrubbed free of dirt. Helicopter logging would be ideal and should be required where it would be cost effective.

Existing contaminated sites will remain a threat as long as they are allowed to regenerate to cedar. The severity of the threat is proportional to the amount of cedar present. Resources to treat such sites probably will be limited except where salvageable timber is present. An effort should be made to keep as many of these areas as possible completely free of cedar regrowth to allow time for the fungus to die. Contaminated sites near substantial, healthy cedar stands on elevated ground should be cleared of cedar and, where possible, fenced to exclude potential carriers. All contaminated sites should be posted with appropriate signs cautioning against thoughtless entry.

*Working when the environment retards infection.*—The forest environment of the Port-Orford-cedar region is favorable for *Phytophthora lateralis* most of the winter and never threatens the life of the fungus. In summer, the fungus either is sheltered from drought within living roots or is in the dormant spore form in the soil.

Fungal activity, as opposed to death, is greatly limited, though, by summer drought. Active spread of zoospores begins after soils become saturated in the autumn. Zoospores are readily detected in streams in late autumn and in winter after soil aquifers become charged, but during the summer the zoospores cannot be found in the streams and presumably are absent. Passive spread occurs naturally by chlamydospores only when soil is wet enough to adhere to animals or machines, or during floods. The primary effect of environment on the epidemic is to regulate periods favorable for sporulation, spread, and infection. Periods conducive to disease spread are longer in the north and towards the coast, where they combine with the greater abundance of cedar to aggravate the epidemic.

Forest operations on cedar sites must be conducted only when soils are dry enough that they will not stick to equipment. This may never occur in some wet locations, and rigid, alternative sanitary measures will be required. Duration of safe periods will vary with local weather, topographic location, and from place to place even during the safer summer months.



*Regulating disease transmission.*—Carriers of root rot spores are more easily controlled by management than are the other factors. The root rot fungus has been hauled around in excavation and earth work, in shipment of plants in infested soil, and in use of river gravel on roads. Spillage and drainage from these sources contaminate roadside ditches and streams. This contagion is perpetuated and increased as cedars become established and then infected in the frequently worked soil along the road and ditches. Survival of *Phytophthora* on any road surface probably is poor, but cleaning of ditches without concern for suitability of dump sites, and grading of the road surface or shoulders brings the fungus out of the ditches and spreads it. At times, most roadsides in the epidemic area are infectious. Front-end loaders, back-hoes, and other equipment that periodically work in the ditches are particularly active in spreading the fungus.

Roadside contagion contaminates logging machinery, trucks, and off-road recreational vehicles as they are unloaded, loaded, or cross the ditches. This equipment carries the fungus into the woods and broadly over the land. Trucks using newly graded rock roads and certainly dirt roads may become contaminated in wet weather and move the fungus for miles along the road. All of these inoculum sources drain to the lowlands to infect cedar along the streams or wherever water collects.

A first essential step for all areas where work is scheduled, and ultimately all areas where cedar is a consideration, is preparation of detailed maps that locate all Port-Orford-cedar timber and road segments, ditches, swamps, and streams that are infectious; this work is in progress for some USDA Forest Service lands. If these maps are kept current and are regularly consulted, planning and day-to-day management for sanitary operations will emanate from them. The maps can be checked, for example, to assure that infectious, dirty machinery, in the absence of pressure cleaning, is moved only to another infectious site, or away from cedar production areas.

Viable fungus should be absent from warm, dry (dusty) roads and probably would not survive long in moist soil dropped on such a road in summer. The same soil falling into a ditch or onto the forest floor could be dangerous. Consequently, machinery should be cleaned between jobs in summer as well as in winter. Inoculum on animals probably is not exposed to extreme heat or drought. Survival time on the leg of an animal could be fairly long in winter. This emphasizes the importance of excluding elk and cattle from infested swamps and meadows wherever possible. Abrasion of hooves during an animal's movement should remove contaminated mud within a few hundred meters. Cedar production, as well as unwanted cedar, should be kept away from areas of heavy animal use; likewise, free-ranging cattle should be excluded from areas being managed for cedar.

Appropriate planning of access to lands identified for cedar production should include:

1. Entering units by spur roads that can be abandoned, blocked, or gated after stand establishment.

2. Locating roads below units. High roads, where required, should be over the crest from the cedar production site to limit exposure of the site to infection and to direct drainage away from the site.

3. Engineering all roads to remove water as quickly as possible into unobstructed, natural waterways.

None of the disease-reducing practices applicable to the four components of the root rot epidemic can be carried out completely; however, progress on each will sufficiently supplement the others to result in much forest area that will remain free of root rot indefinitely.

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English Equivalents

	Metric	English
Length	1 millimeter	0.0394 inch
	1 centimeter	0.3937 inches
	1 meter	39.37 inches, 3.28 feet
	1 kilometer	0.6214 miles
Area	1 square millimeter	0.001552 square inches
	1 square centimeter	0.155 square inches
	1 square meter	10.7639 square feet
	1 hectare	2.4710 acres
	1 square kilometer	0.3861 square miles
Volume	1 cubic meter	35.3145 cubic feet
	1 cubic centimeter	0.0610 cubic inch
Weight	1 gram	0.03527 ounces
	1 kilogram	2.2046 pounds
Pressure	1 bar	0.9869 atmosphere
Timber product volume (approx.)	1 cubic meter	176 board feet, 0.39 cord
Basal area per land area	1 square meter per hectare	4.33560 square feet per acre
Volume per area	1 cubic meter per hectare	0.1558 cords per acre,
		71.457 board feet per acre <sup>30</sup>
		14.2913 cubic feet per acre
Temperature	degrees Celsius	(degrees Fahrenheit – 32)/1.8

<sup>30</sup> 1 cubic foot = 5 board feet

Source: Munns and others 1949.



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## Appendix

Kellogg's description of Port-Orford-cedar as *Cupressus fragrans*, quoted below, contains apparently the earliest published information about the forests and their use (Kellogg 1857, p. 115-116). The latitudes cited are incorrect.

\* \* \* \* \*

5 October 1857

San Francisco

Dr. Kellogg read the following paper, with appended remarks by Dr. Beardsley.

Dr. Kellogg exhibited a drawing and specimens of a new species of Cypress.

CUPRESSUS FRAGRANS, Kellogg; or the Fragrant Cypress.

*Branchlets*, four-sided, somewhat compressed, densely crowded, subdivisions numerous, with a frond-like arrangement; larger branches roundish, slightly compressed laterally, flexuose; *bark* madder brown; *leaves* diamond-acute and aculeate, shining, bright, vivid green, carinate, an oblong resinous gland along the back, appressed, imbricated in four rows; older leaves on the intermediate branches long, decurrent; point awl-shaped, incurved.

*Cones* pedicilate on long, scaly footstalks, similar to the branchlets, somewhat elongated, globose cinnamon color, size of a hazel-nut, composed of about nine peltate scales; center depressed; margin thickened and rounded; disk corrugated and rough, a sharp, transverse ridge divides it somewhat above the center; the mucro broad, thin or flat, pointed, fragile, curved outwards and pointed towards the apex; scales irregularly five-sided.

Seeds broadly winged all round, waved, oblique, scooped; base of the smooth cylindrical kernel portion prominent; apex emarginate, mucronate, bright cinnamon color.

This species bears the nearest resemblance to *C. lawsoniana*, but differs from it most strikingly in the brighter green of its foliage and its far denser branchlets; also in the leaves being narrower, much more angular, sharper pointed; the cones are from one-third to twice the size, more rough, also in color, form, and more sparse distribution, etc.; it is also a tree of larger proportions in all respects. The specific name chosen is intended to express its quality, par excellence. We know of no species so agreeably fragrant; the wood abounds in an oil which exhales a peculiar spicy aroma, in which the ginger odor predominates.

This notable odor has sometimes given it the common name of "Ginger Pine" among lumbermen. Some speak of it as "White Cedar"; in the market it is also known by the more indefinite name of "Oregon Cedar." The grain of the wood is commonly a fine, close texture, strong and elastic; the annual concentric circles are often as large and distinct as the Eastern white pine (*P. strobus*), showing it to be a tree capable of rapid growth. It has gained a good reputation among carpenters since it has been brought into market properly seasoned; it works easy, and burnishes smoother than the white pine.

We understand suitable machinery is now on the way to this city (S.F.) for the purpose of working this lumber into tubs, pails, and other domestic wares, similar to our Eastern "Cedar Coopers," as that class of mechanics is styled, who work only this species of wood.

The well-known collector and enterprising discoverer of this and several other new species of the conifers—Mr. A.F. Beardsley—has furnished the following observations:



## CUPRESSUS FRAGRANS.

Among the timber trees of the Pacific Coast, the White Cedar, as it is commonly called, of Southern Oregon, is among the most interesting for the beauty of its foliage and utility of its wood. It is found in almost every situation contiguous to the coast, and for several miles inland, but most abundant in moist ground and low hills kept moist by the density of the forest. It nearly fills sections of the extensive forests in the maritime districts of southern Oregon, latitude 52° to 44°. It is mingled with *Abies Canadensis*, *Abies Douglasii*, *Abies Menziesii* [western hemlock, Douglas-fir, and Sitka spruce], and a Silver Fir that I could not designate, it having neither fruit nor flower at the time (May 25th), resembling *Pinus grandis* of Douglass [grand fir]. The trees stand so thick that the light can hardly penetrate the evergreen foliage, and in their gloomy shades spring at every step Rhododendrons, Dwarf Bay, Vacciniums, bearing a delicious red berry, and other shrubs and plants. This tree grows straight, six feet in diameter, 150 feet in height, and nearly destitute of branches for 50 to 70 feet; but when found singly, its long, slender, pendulous branches are retained down nearly to the ground, making the general outline columnar, surmounted by an elongated pyramid. The bark on the young stocks is thin, but as they grow old becomes thick, furrowed, and of a soft, fibrous texture, not unlike that of *Taxodium sempervirens* [red-wood], of a chocolate color. The color of the wood is white, rather heavier and firmer than white pine (*Pinus strobus*), which it much resembles; it is strong and durable, fine grain and easily wrought. It has a strong, fragrant, spicy odor, which it retains for a long time. This characteristic has suggested the name of Fragrant Cypress. The lumber made of it is of the best quality, being very clear from knots. It is extensively used in San Francisco for joiners' work, and commands the highest price in the market. It is preferred for clothes presses, chests, etc., having the same properties in this respect as camphor wood (*Laurus camphora*) in keeping away moths and other insects. It has been used in boat-building, and is highly recommended by those who have used it for this purpose. It would make excellent timbers in ship-building, where extra durability is required. There is no more valuable timber found on the Pacific Coast—the famous sugar pine (*Pinus lambertiana*) not excepted. From the latitude in which it is found, it is unquestionably hardy, and its cultivation would be a valuable acquisition to the Atlantic States and Northern Europe.



**Zobel, Donald B.; Roth, Lewis F.; Hawk, Glenn M.** Ecology, pathology, and management of Port-Orford-cedar (*Chamaecyparis lawsoniana*). Gen. Tech. Rep. PNW-184. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985**. 161 p.

Information about the biology, diseases, and management of Port-Orford-cedar was collected from the literature, from unpublished research data of the authors and the USDA Forest Service, conversations with personnel involved in all facets of Port-Orford-cedar management, and visits to stands throughout the range of the species. Information is summarized and presented regarding species characteristics, distribution, environment, vegetation, autecology, usage, past management, and the biology and effects of the most important pathogen. Recommendations for managing the species in the presence of this pathogen, *Phytophthora lateralis*, were developed. Presence of this introduced pathogen will complicate the management of Port-Orford-cedar and somewhat reduce the area where it can be grown, but production of future crops of cedar should be possible given careful, consistent application of the guidelines presented.

**Keywords:** Autecology, silvical characteristics, silviculture, root rot, ornamental trees, Port-Orford-cedar.



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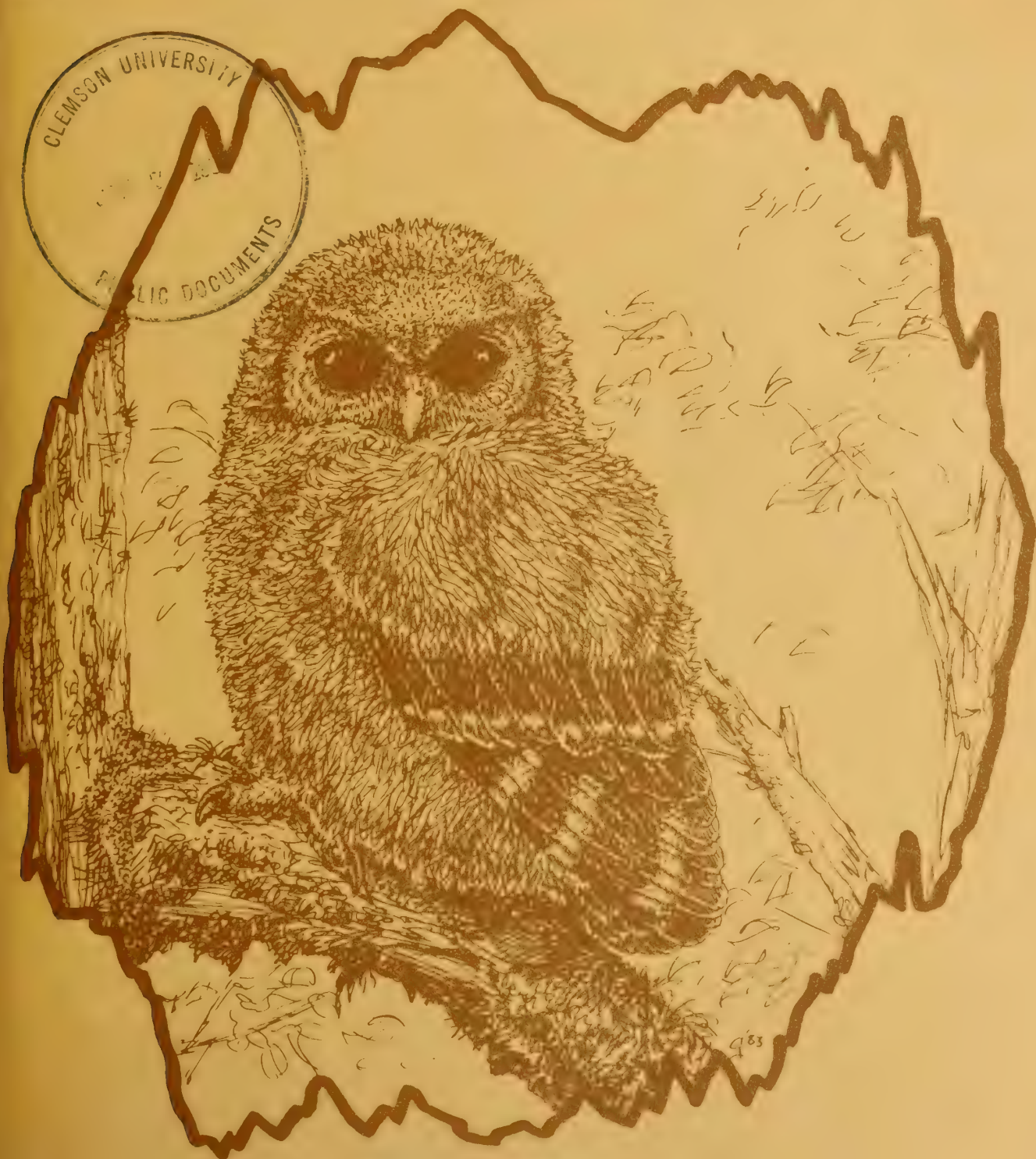
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Ralph J. Gutiérrez and Andrew B. Carey  
Technical Editors

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## INTRODUCTION

RALPH J. GUTIÉRREZ AND ANDREW B. CAREY

The spotted owl, Strix occidentalis, has become a species of concern to ornithologists, wildlife biologists, foresters, and environmentalists because of its apparent need for old-growth coniferous forest in the Pacific Northwest. Because of the concern about spotted owls, a symposium was convened by the Cooper Ornithological Society during its annual meeting in 1984.<sup>1/</sup> The society wished to bring concerns about spotted owls before public, scientific scrutiny. Gutiérrez was asked to arrange the symposium, and Carey was invited to cochair the symposium. Together, we expanded the objectives of the symposium and planned this publication.

The symposium was organized into three sections: management, research, and theory. We felt that an understanding of the laws and regulations governing Federal land management, the state of spotted owl management, the biology of spotted owls, and the predictions of ecological theory were all essential for planning and evaluating future research and management for the spotted owl. We wished to bring this information together in an arena of unconstrained discussion and exposition of ideas. Thus we invited both managers and researchers dealing with spotted owls and theoretical biologists who did not have experience with the spotted owl. Because we had limited time for presentations, not all papers published here were presented at the symposium. We have included the unrepresented papers to ensure a published report that would be a complete treatment of spotted owl research and management in the Pacific Northwest.

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<sup>1/</sup> The 54th Annual Meeting of the Cooper Ornithological Society, 1984 June 19-23, Arcata, CA.

PLANNING AND MANAGING FOR THE SPOTTED OWL IN THE  
NATIONAL FORESTS, PACIFIC SOUTHWEST REGION

W. Dean Carrier

**ABSTRACT:** The spotted owl (Strix occidentalis caurina) has been listed as a sensitive species by the Pacific Southwest Region USDA Forest Service. Past and present studies and surveys have led to the development of a region-wide network of owl territories to comply with the maintenance of viable populations as required by the National Forest Management Act. A brief explanation of the network is included.

HISTORY

In 1973 and 1974, the California Department of Fish and Game and the USDA Forest Service funded an inventory of spotted owls to better understand the status of this species in California. This work was carried out by Gould (1977) and resulted in a state-wide population estimate of 192 pairs in five major population concentrations.

During this period individual Forests also began to assess owl populations and habitats and to consider owls in Forest multiresource management activities. Fairly intensive surveys of suspected owl habitats were carried out in at least four National Forests.

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Following the passage of the National Forest Management Act of 1976 (NFMA) and the issuance of the regulations implementing it, the Forest Service began to assess many wildlife and fish species to ensure that viable populations were being maintained, as the Act requires. The spotted owl, because of its purported need of old-growth coniferous habitats, became the focal point of this requirement.

In 1978 the Oregon Interagency Task Force developed a habitat management plan and population requirements for spotted owls on public lands in Oregon. The Pacific Southwest Region followed this lead and began to assimilate data on spotted owl populations and habitat use in National Forests in California. Between 1978 and the present (1984) the Region has initiated, funded, or assisted in no less than 10 individual research projects or status evaluations of spotted owls.

Because the Pacific Southwest Region chose to treat both subspecies of spotted owl (Strix



occidentalis caurina and S. o. occidentalis) identically, the system used is based on the Oregon-Washington Interagency Wildlife Committee's plan with one major exception. This exception is that the actual assessment and allocation of numbers of territories is relegated to the individual Forests.

#### PLANNING STRATEGY

Using known habitat requirements, as taken from available research data, the task of identifying the numbers and networks of territories to be maintained was assigned to each Forest. To determine these population goals, the Regional plan established guidelines for developing an interacting network of spotted owl territories that would be distributed throughout the geographic range of the species in California north of the Tehachapi Mountains. The criteria provide for grouping, spacing, and specific characteristics of spotted owl territories. The criteria were based on data collected in Oregon and in the numerous local studies that had been conducted in the National Forests of northern California, and on the west slope of the Sierra Nevada range. Habitat requirements were based heavily on the studies by David Solis in the Six Rivers National Forest and by Steve Laymon in the central Sierra Nevada.

It must be stressed that the development of a Regional network, based on a predetermined set of habitat conditions necessary to provide for spotted owl occupancy, was mainly an exercise in modeling National Forest management activities as they relate to and interact with other resource and land uses. In other words, on-the-ground maintenance of individual territories may differ under the standards developed for Land Management Planning. As with most species, local habitat conditions and long-term adaption to specific situations may well be important factors in the success of individual pairs. Broad standards and guidelines cannot encompass all these factors; thus, local adjustments are necessary when actively applying these guidelines to specific areas of land. The modeling assesses the overall costs in terms of other forest resources of maintenance of spotted owl habitat, and on-the-ground application provides for the actual needs of the individual pairs making up this network.

The system for spotted owl habitat maintenance in the Pacific Southwest Region was based on the best information available. This is not to say that we have all the answers; however, our methods were designed to provide for the currently documented needs of this species. Research in the Pacific Northwest and California was reviewed and used in the development of our criteria. The pioneering work of the Oregon Interagency Spotted Owl Task Force and the subsequent development of the guidelines for maintaining viable populations of spotted owls in that State were major factors used in the development of the Pacific Southwest Region's system.

#### SPOTTED OWL TERRITORIES

The first level of the network is the territory. Territories are areas suitable for maintaining one breeding pair of owls. The ecological characteristics of territories have been determined through research and then translated into vegetative components. For the most part, a territory is comprised of a core area within which the nest site, or probable nest site, is located. This area is to contain 300 acres of suitable habitat. If this amount is not available, the existing stand is maintained. In addition to this core area, an additional 700 acres of habitat within 1-1/2 miles of the nest site will be maintained in no more than three parcels, one of which must suffice as an alternate core area.

#### GROUPED TERRITORIES

The second level of this system is the grouped territories (formerly called Spotted Owl Management Areas or "SOMAS"). These are normally comprised of three individual territories spaced within 1-1/2 miles of each other. Some overlap is allowed in providing acreage requirements for the three territories.

#### FOREST NETWORK

The third level of the system is the Forest network. This provides for a system of interacting groups of territories spaced throughout the known geographic range of the spotted owl in that Forest. The network provides for spacing of these groups between 6 and 12 miles apart although single territories can be no further than 6 miles from adjacent ones.

#### INTERACTING NETWORKS

The fourth level is the interacting network between National Forests and other public and private land areas maintaining spotted owl habitat. Forests are required to coordinate with adjacent land managers and their networks are reviewed and approved by the Regional Forester.

#### CURRENT STATUS

Territories for spotted owls have now been delineated in all National Forests, with the exception of the five southern Forests where all known territories will be protected. Using currently accepted survey techniques, territories are presently being verified and boundaries further refined.

The network for National Forest lands in California will provide for approximately 500 pairs. This is exclusive of those pairs that are not a part of the network, but are protected by other land management constraints (e.g., wilderness) and those owls in the five southern Forests. Other resource management agencies and

private lands will provide additional territories to add to the overall maintenance of spotted owls in California.

#### DISCUSSION

The managing of lands to provide for the needs of late vegetative successional species is a new and inexact art, at best. For years, we have had the ability to set back succession for the enhancement of deer, quail, and pheasants; to modify habitat for turkeys, grouse, and elk; or to protect habitats for many other species. There is, however, little evidence of purposeful management to speed up or manage for vegetative succession to provide for those habitats that are developed at the climax end of succession.

In implementing this system we are assuming that the spotted owl will maintain viable populations over time. But, how will we know if the system is working? What additional research is needed to assure this? Are known changes caused by land

management activities or a natural sequence of events? These are but a few of the many questions that are asked of us as we try to measure the exactitudes, demanded by the scientific community, with experimental land management schemes based on state-of-the-art information. It is doubtful that there will ever be "enough" information. As natural and human-caused changes occur in these ecosystems, wildlife population will fluctuate accordingly, but probably not altogether predictably. Who will be the one to decide whether global climatic changes, as predicted by some hydrologists, or artificial habitat changes are responsible for population fluctuations in species.

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HISTORY AND CURRENT STATUS OF SPOTTED OWL (STRIX OCCIDENTALIS) HABITAT  
MANAGEMENT IN THE PACIFIC NORTHWEST REGION, USDA, FOREST SERVICE

Philip L. Lee

ABSTRACT: As information has become available on the status of the spotted owl and its habitat needs, the emphasis on managing for the owls has increased on National Forests. Management of old-growth forests has evolved from rapid conversion of the stands to young timber to the acceptance of the need to retain this special habitat for species such as the spotted owl. Detailed direction for the assessment and development of spotted owl habitat during Forest Planning has been given to National Forest Supervisors by the Regional Forester.

INTRODUCTION

Prior to 1970 little was known about the spotted owl (Strix occidentalis) or its habitat in the forests and it was not given any priority in management of National Forests. What little data existed on the owl indicated it was rare and that few sightings had been made. During the early 1970's, as work progressed on legislation for the management and protection of threatened and endangered species, the spotted owl was proposed as "threatened" by the USDI Fish and Wildlife Service (U.S. Department of Interior, Fish and Wildlife Service 1973).

As more people began to look for the owl, and particularly as it became the object of graduate

studies, enough was learned about it to question the need for a Federal listing. As a result the owl was not listed at the Federal level but was classified in Oregon as threatened and in Washington as a sensitive species. The spotted owl was given the designation "sensitive" by the Regional Forester, Pacific Northwest Region of the Forest Service (Region 6), and thus was afforded special consideration by management.

Following passage of the National Forest Management Act in 1976 regulations were written for implementation of the Act. These regulations gave special emphasis to the spotted owl because it met many of the criteria for a "management indicator species". Those criteria (Code of Federal Regulations, 36 CFR 219.19(1)) were: (1) that decreases in spotted owl populations indicated potential negative effects of planned management programs; (2) the owl was on the threatened species list in Oregon; (3) the owl was a species of special interest; and (4) the owl represented other species that were dependent upon a major biological community, the old-growth forest.

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In the short time that the spotted owl has been of special interest a lot of information concerning its life history and habitat requirements has been collected. New information has required a continual change in management direction by Federal land managers. This change is evident in the numerous memoranda and letters between the various agencies and interest groups and in direction being developed for Forest Planning, which I review in this paper.

#### EARLY PLANNING AND MANAGEMENT STRATEGIES

It is not my intent to go into the details of the early planning efforts regarding numbers of owls or habitat requirements. It is important to note, however, the evolution of acceptance of biological information and the development of direction for management of National Forest lands for spotted owls.

An interagency committee made up of biologists from the Forest Service, Bureau of Land Management, Fish and Wildlife Service, Oregon Department of Fish and Wildlife, and Oregon State University was formed in 1973 to prepare the first Spotted Owl Management Plan. Objectives of the plan were to determine the number and distribution of spotted owls in Oregon and to recommend habitat management practices. The recommendations coming from this first effort were so controversial that on August 16, 1973, the Regional Forester (Region 6) and the State Director of the BLM in Oregon issued a joint statement that it was undesirable to retain 300 acres of old-growth timber around every known spotted owl nest site. Reasons given were: "(1) rigidly cast prescriptions tend to become the accepted practice...; (2) it appears reasonable to assume that the present old-growth stands located within acceptable elevation limits, contain spotted owl populations...; (3) we are confident that further analysis will verify that sufficient old-growth timber stands exist to provide interim...protection...; (4) determination of the desired State-wide production level...should be resolved before total protection of all sighting areas...is undertaken...and; (5) the management by individual animal location philosophy, when applied to all species... presents a land management spectre of considerable magnitude." Management of old-growth timber is a sensitive issue, and there was a desire by some to liquidate the old growth and replace it with young forests. Agency managers were cautious in making decisions that set aside large acreages of old-growth forest until more evidence supported the need.

During the next 3 years evidence continued to come from research and in 1976 the Regional Forester issued direction that "Known nesting sites will be protected until BUMP'S (Biological

Unit Management Plans) were developed..." (memorandum from Region 6 Director of Fish and Wildlife Management November 24, 1976). At this same time the BLM suggested that several enclaves where birds were concentrated should be set aside and not harvested for 10 years, during which time investigation would continue.

Management recommendations and a statewide goal of 400 pairs of nesting spotted owls were established from the first Oregon Spotted Owl Management Plan. In January 1977 the Oregon Endangered Species Task Force recommended to the Regional Forester a proposal for interim spotted owl guidelines. These guidelines, supplementing the 1976 long-range goal of 400 pairs of spotted owls in Oregon were: (1) for one year--1977--protect all nests and areas where the owls had been sighted; and (2) during that year the task force would develop objectives and management prescriptions to meet the goal and also identify the number and distribution of habitats needed to maintain a viable population in Oregon.

In May 1977 the Regional Forester responded to the task force that the National Forests would protect spotted owl habitat as recommended except where timber sales already existed or were planned for sale in 1977. The task force was able to keep its commitment and issued a review copy of the "Spotted Owl Management Plan" on November 3, 1977. The intent was to continue to obtain data and update the plan as needed. The next update occurred in May 1979. Biologists from the State of Washington also joined in the planning process and there is now an Oregon-Washington Interagency Wildlife Committee that considers matters pertaining to the spotted owl, along with other concerns.

Region 6 Spotted Owl Management Guidelines as based on the management plan, were appealed by the Oregon Wilderness Coalition on the assumption that spotted owl habitat would not be adequately protected. As a result of this appeal, a new effort was made to insure that minimum viable populations would be protected while Forest Planning was in process. The details for this action were described by memoranda in 1980 from the Regional Forester to Forest Supervisors. In March 1981 the Interagency Committee recommended that the guidelines be revised to include the option of providing 1,000 acres of old-growth timber per pair until research more clearly defines the habitat needs of the owl.

In May 1981 a "Draft Pacific Northwest Region Plan" was issued by the Regional Forester. This plan included the proposed revision of the Oregon Interagency Spotted Owl Management Plan. This document set recommendations on size and distribution of habitat and populations by ownership and described spotted owl habitat. In May 1984 the draft became the "Regional Guide

for the Pacific Northwest Region."<sup>1/</sup>  
Direction for spotted owl habitat management planning is included in that document and is discussed later in this paper.

#### CURRENT NATIONAL DIRECTION

Recent U.S. Department of Agriculture direction that affects the spotted owl is Departmental Regulation Number 9500-4 dated August 22, 1983. The following excerpts show how this regulation emphasizes the requirements of management and planning under the National Forest Management Act.

"It is the policy of the Department to assure that the values of fish and wildlife are recognized, and that their habitats...are recognized and enhanced, where possible...

"A goal of the Department is to improve, where needed, diverse, native...populations of wildlife...while fully considering other department missions...

"Habitats for all existing native...species... will be managed to maintain at least viable populations of such species...habitat must be provided for the number and distribution of reproductive individuals to ensure the continued existence of a species throughout its geographic range.

"Habitat goals...will be established and implemented. This will be accomplished through the Forest planning process...Habitat goals will be coordinated with State Comprehensive Plans developed cooperatively."

The Secretary established a Fisheries and Wildlife Issues Working Group to monitor implementation of the regulation and to coordinate management with other Federal and State agencies. This direction was incorporated in Forest Service Manual 2603 in June 1984 and the policy for "Wildlife, Fish and Sensitive Plant Habitat Management" was updated.

#### CURRENT FOREST PLANNING DIRECTION IN REGION 6

In the draft regional plan each Forest was assigned a number of pairs of owls to be used in development of the Forest plans. These numbers were to be tested in the planning process to determine their validity. A total of 375 pairs were assigned to the Forests, 263 in Oregon and 112 in Washington (the 400 pairs for Oregon mentioned earlier included all ownerships, not just National Forests). These numbers represented the minimum viable populations. In

addition, four population levels representing different management alternatives were developed and Forest Supervisors were instructed to model at least the minimum and the minimum plus 30 percent when assessing the impacts on other resources. This direction was, in part, a result of a task force recommendation following the appeal of the Oregon Wilderness Coalition. This action brought a response from the Northwest Timber Association members who strongly protested the consideration of an area 1,000 acres in size.

On September 19, 1980, the Regional Forester clearly stated to Forest Supervisors in a memorandum (2670), that "...you not forgo your options to manage for owl population levels in your Forest Plan other than your tentative allocation in response to public involvement..." There will be a continuing public involvement process as Forest Plans are developed, and any long-term decisions concerning spotted owl habitat will follow this process.

In April 1983 Region 6 established a task force to address concerns about the assumptions of models that were used to simulate management that would meet minimum management requirements for wildlife benchmark assessments (a benchmark is a habitat base to which all alternatives are compared to show the effects of alternatives on other resources and on the population of a species selected). Reviews by the Chief and the Pacific Southwest Region of the Forest Service raised some questions about the two methods used to model spotted owl habitat management. The two approaches used were: (1) to dedicate the areas to spotted owl management and defer timber harvest as long as the area meets habitat requirements; and (2) to manage the areas for timber while meeting minimum requirements for the owls. The dedicated method simply sets the habitat aside and no programmed timber harvest occurs. The managed approach provides for timber harvest over a long rotation either as clearcuttings or harvesting individual trees.

The task force determined (unpublished report) that two variables affected the efficiency of timber management while managing spotted owls: (1) the definition of old growth, especially the rotation age; and (2) the size of the old-growth stand. Because of this and other studies for different Forests, Region 6 planning efforts will evaluate both methods or a combination where appropriate.

On February 9, 1983, the Regional Forester sent "Regional Guidelines for Incorporating Minimum Management Requirements in Forest Planning"<sup>2/</sup> to the Forest Supervisors. The reason for Regional direction for minimum management

<sup>1/</sup>Unpublished Administrative Document, 1984, "Regional Guide for the Pacific Northwest Region", on file, Pacific Northwest Regional Office, USDA Forest Service, 319 S.W. Pine Street, Portland, OR 97208.

<sup>2/</sup>Unpublished Administrative Document, 1983, "Regional Guidelines for Incorporating Minimum Management Requirements in Forest Planning," by Jeff M. Sirmon, Regional Forester, Pacific Northwest Regional Office of the USDA Forest Service, 319 S.W. Pine Street, Portland, OR 97208.



requirements (MMR) for wildlife was to insure consistency across the Region in meeting National direction. MMRs also serve as baseline constraints for developing benchmarks and alternatives. These MMRs were not to be construed as alternatives in themselves. The number of spotted owls designated for each Forest was based on Region-wide information. Because these numbers were only approximate, each plan alternative would be measured against the MMRs and a determination made whether that alternative was meeting the intent of the law.

Using this direction, the Forests in Region 6 began to choose the areas that would be managed for spotted owls to meet the MMRs. They also began to develop distribution patterns that would provide for interaction between the owls. The guidelines incorporated the latest information from the Oregon-Washington Interagency Wildlife Committee.

Following a review of the approach to MMRs that several Region 6 Forests were using it was determined that some items needed clarification. On April 16, 1984, this clarification and some additional direction was sent to the Forests. Emphasis was placed on habitat distribution as a key to minimum viable populations. Criteria for distance between spotted owl habitats had been established. A requirement to connect three or more habitats whenever possible was added. Following this direction, the minimum viable population goal for spotted owls increased from 399 pairs to 530 pairs.

The MMRs were developed over several months using data from spotted owl research and the advice of professional wildlife biologists and planners from all levels of the Forest Service. A brief review of the planning of the forests with spotted owl habitat reveals the following:

1. All Forests are using a grid pattern as a planning model.
2. A few (41) habitats will be managed for timber over a long-term harvest plan.
3. Most (489) habitats will be dedicated to old-growth forest and will not be harvested so long as they are suitable for spotted owls.
4. Of the 530 sites, 413 currently contain enough old-growth forest to make them suitable as spotted owl habitat.
5. And, 117 sites have potential as owl habitat but are not currently suitable because of the age of the timber. The particular age used as a determining factor varies by forest but a forest generally becomes suitable for owl habitat between 140 and 170 years of age.
6. There are 374,417 acres of commercial forest affected by this management or about 4 percent of the commercial forest base of those Forests involved. (This data is tentative and subject to change during the planning process.)

Considerable refinement and expansion was done to plan for spotted owl habitat management in the final Regional guidelines. Following is a summary of some of the guidelines:

1. The northern spotted owl will be considered a "management indicator species" in Forest planning.
2. To ensure that viable populations will be maintained, habitat must be provided to support at least a minimum number of reproductive individuals, and that habitat must be well distributed so these individuals can interact with others in the planning area.
3. Each Forest is directed to:
  - A. Analyze and display the economic effects of providing for a specified number of spotted owls.
  - B. When additional spotted owls are discovered, include these owls in the range of alternatives considered in developing Forest plans.
  - C. Incorporate management for spotted owls into the planning process at those Forests that discover owls subsequent to this direction.
  - D. Establish new minimum population numbers for those Forests where habitat is determined incapable of meeting the assigned numbers.
4. The modeling procedures must meet the following criteria:
  - A. Be silviculturally attainable.
  - B. Be designed to ensure maintaining viable populations of owls.
  - C. Provide for proper distribution.
  - D. Meet habitat needs as defined in the proposed Spotted Owl Management Plan (March 6, 1981) and the Regional MMRs (February 9, 1983).
5. One of the following methods will be used to model the effects on timber yields:
  - A. Dedicate the area to old growth.
  - B. Designate the area to management over an extended rotation designed to meet habitat needs.
  - C. Designate the area to uneven-aged timber management that meets habitat needs.
  - D. Designate the area to some combination of the above systems or manage different areas under different systems.
6. At least two Forest plan alternatives relating to spotted owl management will be



evaluated. One alternative will evaluate the Forest's share of the minimum viable population for the Region and the second will evaluate the minimum plus 30 percent. Other alternatives will be considered where indicated to meet multiple-use objectives.

Following is a summary of events in the evolution of management direction for spotted owl habitat in Region 6.

#### A CHRONOLOGY OF PLANNING IN REGION 6

- Pre-1973 Little interest in spotted owls. Rapid loss of habitat.
- 1973 Formation of Oregon Endangered Species Task Force and recommendations from task force to manage 300 acres around known nest sites; rejection of recommendations by Region 6.
- 1976 Direction from Regional Forester to protect known sites. Task force recommends 400 sites be protected in Oregon.
- 1977 First spotted owl management plan for Oregon; assignment of 290 pairs to National Forests.
- 1978 Direction by Regional Forester to meet intent of plan for 290 pairs.
- 1979 Region 6 spotted owl management guidelines developed; revised Oregon Interagency Spotted Owl Management Plan.
- 1980 National Forests protecting all known nest sites and verifying location of owls.
- 1981 Revision of management plan. Issuance of draft Regional plan; 263 pairs of owls assigned to National Forests and in Oregon and 112 to National Forests in Washington.
- 1983 Regional direction for determining Minimum Management Requirements in Forest planning.
- 1984 Clarification and revision of 1983 direction; Forests establish new minimums of 530 pairs; Regional guide finalized (replaced document referred to as Regional plan).

#### RESEARCH

Spotted owl habitat often consists of mature or old-growth timber on highly productive sites capable of producing up to 90,000 board feet per acre in a 60-year period. There is a lot of interest in how that land is allocated. Questions, that research can answer, about the conflict between the requirements of the owl and potential timber production have been identified:

How are old growth timber stands identified, inventoried and properly classified?

What happens to old growth when it is put under management?

What mix of old growth, mature, and other age classes is acceptable to the owl?

What are the upper and lower acreage limits that affect the suitability of the site for owl habitat?

What is the upper limit on acceptable disturbance before the site loses its habitat capability?

What is a minimum viable population of spotted owls and what is its distribution?

What are the dispersal rates and distances by sex and age of the spotted owl?

#### SUMMARY

The spotted owl jumped from obscurity to National prominence in a few years. The reason for this is the owl's affinity for old-growth timber along the west coast. Continued research is needed to determine the allocation of spotted owl habitat among the owl, other old-growth dependent species, and timber production. State and Federal agencies continue to plan these allocations. Cooperation between the agencies, private land owners, and persons with an interest in the owl and its habitat is essential if a balance between the timber productivity of these sites and a stable population of owls is to be achieved. The agencies involved are seeking and using all available information in planning for the future of these resources.

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IMPLEMENTING A SPOTTED OWL MANAGEMENT PLAN:  
THE GIFFORD PINCHOT NATIONAL FOREST EXPERIENCE

William C. Ruediger

**ABSTRACT:** Managers faced with implementing a spotted owl management plan should anticipate the long-term realities of loss of habitat from natural and human induced causes, the necessity of building in flexibility to accommodate changes, the need to measure suitability of the actual habitat and use by spotted owls prior to making land allocations, and the role of monitoring.

INTRODUCTION

Over the last 6 years the Gifford Pinchot National Forest, Pacific Northwest Region, has been in the process of developing a spotted owl management plan. The objective of the plan is to maintain spotted owls, and other species that utilize or require mature or "old-growth forest conditions," throughout their existing range in the Forest. During this period of change and exchange of facts and philosophies, certain realities have become evident and some far-reaching and complex challenges have surfaced. The conclusion is that the challenges are growing each year and the options for solving these challenges are decreasing. Decisions being made today are going to dictate options and success rates for tomorrow, and we cannot wait to make these decisions. Perhaps by looking at the experience in the Gifford Pinchot, other

biologists and managers can evaluate their situations and make better decisions.

There are several critical elements land managers and biologists should consider when developing and implementing a spotted owl management plan. These critical elements may have universal application across the range of the spotted owl or, on a broader perspective, they seem to apply for any species being managed near minimum population levels.

The key features of a spotted owl management plan include:

1. The quantity of habitat provided.
2. The quality of habitat provided.
3. The distribution of habitat provided with emphasis on key axis habitats which if lost could isolate geographic populations.
4. Demonstrated use by spotted owls (verification).
5. The ability of the individual management areas and the overall plan to absorb unforeseen impacts.

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The following documents show how these critical elements have evolved from and affected the Gifford Pinchot National Forest's spotted owl management program between 1978 and 1984.

#### QUANTITY OF HABITAT

Both the number of spotted owl management areas provided and the size of each area are important. In 1978, the Gifford Pinchot National Forest was providing 40 acres of habitat around each spotted owl nest site. As only one nest site was known when, the total area managed for spotted owls was 40 acres.

In 1979, the policy was changed to provide habitat for 39 pairs of spotted owls. Each pair was allotted 300 acres of old growth or, if this was not present, mature habitat in the Douglas-fir/hemlock vegetative zone. The basis for 300 acres of habitat for each pair was the Oregon Spotted Owl Management Plan.<sup>1/</sup> Whenever possible, management areas where spotted owls were known to exist were given priority over adjacent areas without known pairs. The total area needed to sustain this population level was 11,700 acres.

In 1980, the Gifford Pinchot National Forest made a decision that all spotted owl management areas would be inventoried prior to selection to evaluate habitat suitability. During this time, Mount St. Helens erupted and destroyed approximately 24,000 acres of old growth and mature Douglas-fir/hemlock type forest, much of it known to contain spotted owls. A new spotted owl management strategy was prepared, this time utilizing 45 pairs of spotted owls and 540 acres of habitat per pair (300 acre nesting core plus three 80-acre foraging areas). The basis for using this criteria was the Oregon Interagency Spotted Owl Management Plan.<sup>2/</sup> The total area necessary to sustain this population was 24,300 acres.

The Oregon Interagency Spotted Owl Management Plan was revised in 1981,<sup>3/</sup> reflecting the then-current consensus that 1,000 acres of old-growth habitat was necessary for each pair. In 1982 the Forest told Ranger Districts that 1,000 acres of habitat would be maintained for all pairs identified in the Spotted Owl Management Plan, and that 1,000 acres would be maintained for all new spotted owl pairs located

until the Forest's plan was completed. The number of acres necessary to sustain the spotted owls identified in the Gifford Pinchot National Forest Spotted Owl Management Plan and the Mount St. Helens Land Management Plan was 47,000 acres. An additional 7,000 acres received temporary reprieve from timber harvesting as "pair protection areas" pending final disposition in the Forest's plan. The total acreage receiving management emphasis for spotted owls was 54,000 acres.

The situation as of 1984 is that there are now 14 "pair protection areas." The 47 pairs in the Gifford Pinchot Spotted Owl Management Plan and Mount St. Helens Land Management Plan are also being provided for, for a total short-term commitment of 61,000 acres.

There are several scenarios that could be provided for the future, but let me provide what I consider a minimal approach for the Gifford Pinchot National Forest. Recent analysis suggests that the lowest number of spotted owls that could be managed for over the long term, with a reasonable amount of risk, is approximately 52 pairs. At this level, there would be 10 habitats providing flexibility for situations described later in this paper.

There are two ways spotted owl habitat could be managed. The first option is referred to as "dedicated", whereby suitable areas of 1,000 acres would be identified and preserved. The total area necessary to sustain 52 pairs under this type of management would be 52,000 acres, some of which is already being preserved under such allocations as "wilderness" and "national monument".

The second option would consist of managing approximately 2,400 acres under a 240-year rotation to sustain 1,000 acres of habitat suitable for one spotted owl pair. If 80 percent of the spotted owl management areas were managed with an extended rotation and 20 percent managed as dedicated (in wilderness or national monument status), the acreage necessary to sustain 52 spotted owls would be 110,800 acres.

#### QUALITY OF HABITAT

Occupied spotted owl management areas were measured in the Gifford Pinchot National Forest and the following stand characteristics were observed:

1. Twenty to 40 large trees per acre (30-in. diameter at breast height (d.b.h.) or larger).
2. Eight or more large snags per acre (20-in. d.b.h. or larger).
3. Twelve or more downed logs per acre (12-in. d.b.h. or larger).
4. Multistoried stands with at least 80 percent canopy closure.

In 1980, the Forest planned to inventory habitat in all areas being considered for spotted owl management. The eruption of Mount St. Helens

<sup>1/</sup>Oregon Department of Fish and Wildlife. 1978. Spotted owl work group meeting, plan on file at the NW Regional Office, Corvallis, OR.

<sup>2/</sup>USDA Forest Service. 1984. Regional Guide for the Pacific Northwest Region. Appendix C, p. C-5/6/7. On file at USDA Forest Service, Region Six, 319 S.W. Pine, P.O. Box 3623, Portland, OR.

<sup>3/</sup>USDA Forest Service. 1984. Regional Guide for the Pacific Northwest Region. Appendix F, p. F-2/3/4. On file at USDA Forest Service Region Six, 319 S.W. Pine, P.O. Box 3623, Portland, OR.



made inventorying impossible over much of the Forest; however, 23 areas were evaluated. Of the 23 areas inventoried, 3 (13 percent) were subsequently determined to be unsuitable because they lacked one or more of the previously described habitat components. The three areas considered unsuitable were replaced with more suitable areas nearby.

Between 1981 and 1984, approximately 25 additional potential habitat areas have been inventoried. Five (20 percent) of these were subsequently determined to be unsuitable and replaced with suitable areas. These areas had preliminary evaluations consisting of aerial photograph reviews and nonmeasurement ground reconnaissance.

Managers who have not measured actual spotted owl habitat parameters can likely assume that 15-20 percent of the areas being considered or managed as habitat may not meet minimum standards.

#### USE BY SPOTTED OWLS

A significant portion of management areas judged to be suitable habitat (even after a habitat inventory) may not be used by spotted owls. For example, in the Gifford Pinchot National Forest approximately 20 percent of the spotted owl management areas have either had to be replaced because use by owls could not be confirmed, or the areas continue to be managed as habitat without owls. If habitat inventories had not been the basis for locating management areas, an estimated 40 percent of the spotted owl management areas selected would not have been suitable.

Spotted owl management plans that are developed with little or no information on habitat or use can be expected to go through major revisions, or they may not sustain expected population levels.

#### DISTRIBUTION OF HABITAT

Distribution strategies must consider availability and suitability of habitat, home range and territory sizes, dispersal distances, and other pertinent behavioral and environmental factors.

In the Gifford Pinchot National Forest, habitat availability has necessitated managing spotted owls above the densities that could be sustained if habitat were uniformly distributed. Theoretically, if my mathematics are close, spotted owls could be managed at one pair per 40,000-42,000 acres, using maximum distances provided in the revised Oregon Interagency Spotted Owl Management Plan. Estimated minimum densities in the Gifford Pinchot National Forest are one pair per 30,000 acres. This density is about 25 percent greater than the theoretical minimum and results from the existing distribution of suitable habitat in the Forest.

When occupancy by spotted owls (verification) becomes a criterion for habitat suitability, many old-growth areas may be excluded. Each additional criterion further limits the selection of choices and will tend to increase the density of habitats managed.

Intermingled private and public land ownerships can also contribute to distribution, management, and other resource impacts. This is a significant problem on many Forest Service and Bureau of Land Management lands. Intermingled ownerships commonly create at least three problems for the land manager. First, the impact on timber resources is increased for the managing agency if all habitat requirements must be supported on half of the available land area, which is a common situation where there is railroad-ceded lands. Second, intermingled ownership may increase the density of owls that must be managed because of restricted availability or suitability of areas that can be selected. Third, management of habitat on federal lands can be hampered by factors such as blowdown and fragmentation, which can result from large areas cutover on adjacent lands.

#### ABILITY OF A SPOTTED OWL MANAGEMENT PLAN TO ABSORB UNFORESEEN IMPACTS

The experiences I have had over a relatively short period of time have convinced me that an important part of a spotted owl management plan is its provisions for absorbing unforeseen impacts such as natural disasters, land ownership or land use changes, and management mistakes. These impacts can be catastrophic, as in the case of the eruption of Mount St. Helens; more often they are subtle and cumulative.

The following are examples from the Gifford Pinchot National Forest of how these impacts can be widespread and significant, even over the relatively short timespan of 5 years.

#### Natural Disasters:

1. The eruption of Mount St. Helens eliminated approximately 25,000 acres of mature and old-growth forests on National Forest lands known to contain a high density of spotted owls.
2. The Christmas Day windstorm in 1983 caused 215 acres of blowdown in six spotted owl management areas, including 75 acres in one core area. This resulted in having to make adjustments in five areas, combine two other management areas into one, and relocate one management area. Blowdown appeared greatest adjacent to harvest units, particularly in locations where habitat had already been fragmented by timber harvesting.

#### Land Exchanges:

1. Land exchanges south and west of Mount St. Helens resulted in relocation of two management areas. The land ownership pattern was intermingled.

2. Land exchanges to the south and west of Mount Rainier National Park will likely result in the loss of one or more spotted owl management areas. The land ownership pattern is intermingled.

#### Management Problems:

An escaped slash fire in 1979 resulted in 1,200 acres of old-growth habitat being burned. A spotted owl management area tentatively planned for this area was moved to another, less suitable area.

#### SUMMARY

Viability and flexibility of spotted owl management plans and strategies will depend largely on:

1. Identifying suitable habitat based on habitat inventory data, verification of spotted owls and evidence of breeding success. If possible, radio telemetry should be used to focus on habitat used by owls in contrast to habitat that may appear suitable but does not receive use.

2. Providing management areas that are larger than the minimum necessary to maintain owls so there is flexibility to adjust for spatial needs and allow for habitat attrition. Reliance on minimum-sized management areas (1,000 acres) carries a high risk.

3. Considering distribution and land ownership patterns to identify key axis areas where geographic populations could be isolated if habitat were lost.

4. Providing an adequate number of management areas so that viability is maintained even if several areas are lost. Emphasis for additional areas should be placed at key axis locations to ensure distribution criteria are met over time. Management plans or strategies that rely on minimum population levels should be considered high risks.

5. Diligent monitoring of critical factors such as dispersal of young, mortality rates, breeding success, spatial and habitat requirements, and changes in habitat caused by natural and human induced causes.

OLYMPIC NATIONAL FOREST SPOTTED OWL HABITAT MANAGEMENT:  
TRANSLATING EVOLVING MANAGEMENT GUIDELINES INTO ACTIONS

Maureen A. Beckstead

**ABSTRACT:** Significant progress has been made in identifying the distribution, abundance, and habitat of spotted owls in the Olympic National Forest. Implementation of the Spotted Owl Management Plan has been complex due to the geography of the Olympic Peninsula, the vagaries of spotted owl behavior, and other resource conflicts. The Olympic National Forest is committed to a more complete, site-specific knowledge of spotted owl habitat use and continues to gather data through monitoring to help refine future management regimes.

INTRODUCTION

It is a task of personnel in Supervisors' Offices of National Forests to identify and clarify, to define and refine management direction and guidelines, and to oversee inclusion of the guidelines in land management planning and field operations. It is a task of personnel stationed at Ranger Districts to interpret and employ management direction and guidelines in project planning and field operations. These tasks are necessarily complex because they are often concurrent, usually iterative, and always interactive.

The implementation of spotted owl habitat management direction and guidelines has been complicated by the fact that this direction has been continually evolving, as has direction for development

of Forest Land Management Plans. This evolution will continue as research and monitoring identify new or more refined information and as Forest Land Management Plans are completed, amended, and revised.

Direction to the Olympic National Forest (Olympic) to manage northern spotted owl habitat is less than 5 years old. Early direction specified that this Forest would maintain a specific number of "known" spotted owl habitats and guidelines were developed that indicated the size and distribution of suitable habitat within each Spotted Owl Management Area (SOMA). Following several changes, later direction specified size and distribution of suitable habitat within SOMAs, minimum and maximum distances between SOMAs, and a distribution that would allow owls in any one SOMA to disperse to at least three other SOMAs.

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Implementation of management direction and guidelines for size and distribution of habitats is complicated by certain geographic features particular to the Olympic. Major features include:



probable geographic isolation from suitable habitat in the Cascade Range; size and shape of lands managed by the Olympic; previous land management and fire history of the Olympic and adjacent landowners.

Add to these features the facts that little information is available regarding spotted owls or habitats on adjacent lands and that spotted owl behavior appears to vary from year to year and area by area. Implementation of a spotted owl management plan may have to employ large doses of "best professional judgment" to meet the intent, if not always the letter, of management direction.

The purpose of this paper is to discuss the techniques and procedures used, the progress to date, and the difficulties encountered in identifying and planning for SOMAs in the Olympic. Also important to discuss is the need for continuing to refine techniques, knowledge, and management direction through monitoring, evaluation, and revision. Because direction, procedures, difficulties, and progress were evolving at the same time, I have chosen a chronological format for this discussion for the sake of clarity.

## IMPLEMENTATION

### Ancient History Through 1977

The earliest direction received by the Olympic stressed inventory of spotted owls. All sightings, nest locations, and acres surveyed were to be reported to the Pacific Northwest Regional Office by July 1977. Interim to the completion of a Spotted Owl Management Plan by the Oregon Endangered Species Task Force, habitat diversity was to be maintained. More specifically, a complete range of successional stages was to be retained in areas of 8,000 to 20,000 acres.

To this time, no inventory of spotted owls had been performed in the Olympic by Forest Service personnel. Howard R. Postovit <sup>1/</sup> conducted the first survey in Washington in 1976. Several of his survey routes occurred in Olympic National Forest and in Olympic National Park.

Postovit surveyed areas of unharvested old-growth forest, mosaics of old-growth and second-growth stands, and uniform second growth. These were divided into five classes by proportion of old growth and 30 routes were randomly selected for survey in each class. Routes walked were 2½ miles long; each route was walked twice while calling owls at 164-foot intervals. If an owl response was heard, Postovit moved three-quarters of a mile before calling again to avoid calling the same bird. Data collected within 327 feet of each owl

location included elevation, topography, tree species, canopy density, approximate stand age, average diameter at breast height (d.b.h.) of overstory trees, and forest class.

Fourteen owls were located at 13 sites on the Olympic Peninsula and 8 owls were located at 7 sites in the Cascade Range. Almost all locations were in old growth; the majority of surrounding areas were more than 66 percent old-growth forest. On the Olympic Peninsula, 9 owls were found on National Forest lands and 5 owls on National Park land. Average slope was 55 percent; all owls were located on western and northeast slopes; elevation ranged from 752 to 3,188 feet on the west side of the Peninsula and from 1,488 to 2,747 feet on the northeast side.

### Survey, 1978

William Brown, Jr., Forest Wildlife Biologist for the Olympic, contracted with Ken Dzinbal, Oregon State University, to conduct a spotted owl survey. The survey was designed to determine the existing geographic range of spotted owls in the Olympic, to provide preliminary information on habitat preferences and owl density, and to refine inventory techniques for future use.

Dzinbal, usually accompanied by Ranger District personnel, ran 417 miles of road transects in over 40,000 acres of suitable habitat; i.e., areas that contained predominantly old growth and that were under 4,000 feet in elevation. Nonroaded pristine old growth and areas predominantly in younger stands were not surveyed for practical reasons.

Owls were located by calling at night for 1 minute every one-quarter mile along a road transect. If a response was received, the observer moved 1 mile before calling again. Data collected at each response location or sighting included aspect, percent slope, elevation, time, percent cloud cover, moon phase, precipitation, wind speed, and temperature.

The survey resulted in a total of 51 responses and 3 sightings, of which 13 may have been male/female pairs, at 38 separate locations. Response locations indicated spotted owl use predominated at midelevation ranges on moderately steep slopes on northwest or southeast aspects. Owl use was different on west and east sides of the Olympic. On the east side, locations of owls averaged 2,750 feet in elevation and occurred only on south, southwest, and southeast aspects. On the west side, locations averaged 1,900 feet in elevation, and 70 percent occurred on north, northwest, and northeast aspects.

Density of owls, based on responses and sightings, were one owl (pair) per 8.9 miles of road surveyed. Area density was calculated from clusters of responses representing three or more owls (pairs). Area densities ranged from one owl (pair) per 1.96 square miles to one owl (pair) per 4.17 square miles. The assumption in 1978 was that spotted owls were rarely known to live separately so that each response was considered

<sup>1/</sup> Unpublished report, 1977, "A Survey of the Spotted Owl in Northwest Washington," by Howard R. Postovit, National Forest Products Association, 1619 Massachusetts Avenue, N.W., Washington, DC 20036

a pair location. More recent survey and research have cast doubt on this assumption.

#### Hiatus, 1979-1980

Though management direction and guidelines were evolving rapidly during this period, activity at the field level consisted of documenting accidental encounters with spotted owls and some nonstandardized surveying of proposed timber sale areas.

In 1979, for the first time, the State of Washington joined the spotted owl planning process and the Oregon-Washington Interagency Wildlife Committee revised the Spotted Owl Management Plan (SOMP). During 1980, a USDA Forest Service task force developed a process to determine various levels of viable spotted owl populations; it was assumed that all owls in Oregon and Washington were one interbreeding population. The Regional Forester adopted the SOMP and forwarded direction to the Olympic to maintain at least 17 SOMAs as a tentative, interim allocation. The Olympic National Forest Plan was to evaluate various alternative management levels. SOMAs were to encompass 1,200 acres of "known" spotted owl habitat and include a 300-acre contiguous old-growth core around a nesting site, plus at least three 80-acre feeding-perch patches nearby in order to implement the SOMP. The Olympic was directed to designate confirmed or suitable SOMAs by July 1981.

Standards for confirming SOMAs and verifying core nesting areas were also developed in 1980.<sup>2/</sup> Confirmation of general SOMA occupancy consisted of two or more visual observations or auditory responses of spotted owls in approximately the same area, 72 or more hours apart, anytime throughout the year. Verification of a core area must be made during the period from March 1 to August 31 and consist of one of the following: one or more visual observation or auditory response of an adult male and female within the same one-quarter square mile area; three or more visual observations or auditory responses of an adult bird in the same one-quarter square mile area, 72 or more hours apart; or location of a nest or recently fledged young-of-the-year birds.

Habitat for all known pairs was to be maintained until the Olympic verified its minimum number of SOMAs. Further, once a SOMA was confirmed, no habitat modification was to occur until the core area was verified. Once the minimum number of SOMAs were verified, Forests were encouraged to maintain habitat for other known pairs to provide for alternative planning levels.

#### Implementation and Planning, 1981

The SOMP was revised in 1981 and the Olympic received direction to establish SOMAs containing a 300-acre core area with an additional 700 acres

of old growth within 1½ miles. These SOMAs were to be distributed no more than 6 or 12 miles apart depending on whether they contained a single pair of owls or multiple pairs. Single-pair SOMAs were acceptable only to meet distribution requirements or where remnant habitat existed. Other direction continued, including the prohibition on habitat modification except that, now, timber sold previous to October 1980 was exempt and available for harvest.

I was transferred to the Forest Wildlife Biologist position in 1981, though I had been working on the Olympic Forest Plan during the previous year. It was already obvious that geography and topography were going to make implementation of the SOMP difficult, at best. The Olympic resembles an elongated doughnut, broken on the west side by extensive areas of State and Indian reservation lands and on the north by private lands that surround the Olympic National Park. Width of the Olympic in most areas is 12 miles or less and rarely exceeds 15 miles. Because of previous, intensive and extensive fire history, as well as a history of lowland timber harvesting, large areas were void of suitable spotted owl habitat, as defined by the Regional Office. Identifying potential SOMAs to provide well-distributed habitat throughout the historic range in the Olympic planning area was impossible. No SOMAs were yet verified, but managing only 17 potential areas out of over 40 response and observation locations caused them to be strung out like beads on a necklace at distances exceeding management direction. Previous inventory of owls and habitat indicated that clusters of owls for multiple-pair SOMAs were extremely rare except on one Ranger District, so that a 6-mile distribution of habitats was the norm. Because the previous survey was conducted only in roaded areas, most potential SOMAs were in conflict with existing or proposed timber sales and were often already fragmented to some degree.

Survey and attempts at verification of SOMAs were reinitiated in 1981. The Forest Supervisor's direction emphasized (1) survey of proposed timber sale areas to comply with the process required by the National Environmental Policy Act; (2) survey of roadless areas or lands dedicated to purposes other than timber management to reduce resource conflicts; and (3) reinventory and verification of areas with a previous owl history.

Surveys were conducted at night between March and September using recorded spotted owl calls amplified from a cassette tape player. Surveyors included personnel from any and every resource area in District and Supervisor's Offices. Crews of two or more drove a predetermined route, stopping every one-quarter mile and calling every few seconds for 5 to 10 minutes at each stop. On trail routes, calls were played every few minutes. Calling generally began 1 hour after sunset and lasted about 4 hours. Response locations or sightings were mapped; time, weather, and comments were recorded.

<sup>2/</sup>Horn, Kirk M, 1980, Information on file at the USDA Forest Service, Pacific Northwest Region, P.O. Box 3623, Portland, OR. 97208, 2 p.



Although 41 responses were received during 332 hours of survey, which compared favorably to 51 responses in 276 hours in 1978 with many locations repeats from 1978, no SOMAs were either verified or confirmed to the regional standards described above. It was noted in 1981 that moving 1 mile from a response or sighting was not always enough, as some observers were followed by owls for several miles, particularly early in the breeding season. Also, about half of the areas where owls were located in 1978 that were checked in 1981 did not produce owl responses.

#### Implementation and Planning, 1982

The Olympic issued direction that verification of at least 17 SOMAs was a high priority so that Forest Plan development could proceed based on site-specific information. The Olympic also agreed to participate in the 2-year spotted owl census organized by the Department of Game, however, and was committed to run eight census routes in the Forest and Park. Funding for these activities was minimal so verification efforts were also limited.

Details regarding procedures used for the State census routes are presented elsewhere (Allen and Brewer 1985). Efforts at verification followed regional standards. Though 40 owl responses were received in 442 hours of survey, only three SOMAs were verified on two Ranger Districts by the end of the season. Two SOMAs were within 3 miles of one another, further complicating the distribution problem. Many response locations repeated those of either 1978 or 1981, or both, but some were new, and again resurvey of old locations produced responses only about half of the time. It was also apparent, through annual responses, that in at least one Ranger District owls were using habitat not considered "suitable" by Regional Office definition.

To proceed with the development of the Olympic Forest Plan, potential SOMAs were allocated to each District according to the following prioritized criteria:

1. SOMAs already verified;
2. Potential SOMAs with a history of previous responses or sightings;
3. Potential SOMAs with no history of occupation, that were needed to meet distribution criteria for suitable habitat, but with few resource conflicts; and
4. Potential SOMAs with no history of occupation that were needed to meet distribution criteria, but either had resource conflicts or habitat not considered immediately suitable.

These potential SOMAs were entered into the Olympic's Total Resource Inventory System (TRI System), which served as the data base for the Forest Plan and the automated mapping system, R-2 Map. From these systems, detailed information could be retrieved for each potential SOMA; information that included number of acres assigned inside and outside the core, elevation, aspect, vegetative eco-class, stand tree size, and stand year of origin. Where there had been any silvicultural exams or

inventory plots within a SOMA, data also included percent of area in trees, shrubs or grass-forb stages, major species, and a history of any management activity or direction.

Following allocation, the extent of conflict with other resource activities became more apparent. For instance, all three SOMAs verified in 1982 contained timber sales already sold as well as proposed sales. One SOMA had timber units sold prior to October 1980 (which were exempt) in the core, including the suspected nest tree. Locations of a radio-collared male from this SOMA showed him to be repeatedly using areas scheduled for harvest within 1 to 2 years. The Olympic is presently in the expensive and time-consuming process of modifying several sales to provide protection for areas of owl use.

The need for continuing refinement and interpretation of management direction coupled with large doses of "best professional judgment" arose along with the immediate and ongoing requests for boundary changes to accommodate other resource needs. A careful balance of priorities was needed to resolve resource conflicts that included theoretical knowledge of life history and habitat use of spotted owls weighed against the ability of managers to accomplish their timber management activities elsewhere.

#### Semi-finally, 1983

The Forest Supervisor for the Olympic issued direction to Ranger Districts to complete verification of their minimum allocation of SOMAs plus one additional area by the end of the 1983 season. Again, the Forest's funding was minimal so that only half of the State's census routes were completed, as emphasis was placed on verification. This direction stemmed from the recognition that planning based on potential SOMAs was a major factor in the difficulties described previously, and that a site-specific knowledge of spotted owl use would lend more credibility to the decision-making process.

During an intensive effort involving 1,577 hours of field work, of which one-third was volunteered 77 responses or sightings were recorded. Fourteen SOMAs were confirmed and nine core areas verified within them. Though the total allocation of 17 SOMAs had been confirmed, the requirements for distribution of habitat could not be met because all but two seemed to be single-paired and because of the geography of the Forest.

Other possible anomalies appeared with the confirmation of two SOMAs in habitat previously considered "unsuitable," one of which produced two fledglings. Special attention was given to this SOMA due to the paucity of old growth within 1½ miles of the nesting area. Much of the Ranger District, including the SOMA area, includes 90-year-old, or younger, stagnated stands ranging from 5,000 to 20,000 stems per acre. Some areas, however, contained old-growth elements such as interspersed larger trees and snags. In an effort to determine the appropriate size and shape of this SOMA, an attempt to determine the



prey base, prey base density, and habitat use by the owls was begun. Department of Game captured, radio-collared, and monitored habitat use of the two fledglings through mid-1984, though the fledglings soon dispersed from their natal area. District personnel and I collected eight pellets from the fledgling roost area. These were analyzed by Murray Johnson, University of Puget Sound, and were found to include nine northern flying squirrels, two red-backed voles, and one adult and three immature bushy-tailed woodrats. I also observed a cached (partial) snowshoe hare while collecting pellets. Funds were requested to determine prey base density in order to estimate the amount of habitat necessary to support the dietary needs of an adult pair and two fledgling spotted owls.

Because of these anomalies, distribution difficulties, erratic occupancy of specific areas, and the long distances apparently traveled by curious, defending, or dispersing spotted owls, the Olympic in concert with the Mt. Baker-Snoqualmie and Gifford Pinchot National Forests cooperatively developed a SOMA monitoring plan with Forest Service research and the Washington State Department of Game. This plan is described in a paper by Carey and Ruggiero (1985).

Meanwhile, regional direction was refined and made more specific, and issued as minimum management requirements for establishing viable populations of spotted owls in the Forest planning process. This direction was used to establish the latest confirmed and verified SOMAs and core areas in the Forest Plan data base during the planning "pause" which followed the Ninth Circuit Court of Appeal's decision regarding evaluation of RARE II areas.

#### Existing Situation, 1984

A summary of the Olympic's data on spotted owl habitat use as of early 1984, included a total of 209 owl responses or sightings at 48 locations. Locations were considered "separate" if they were 2 to 3 miles from any other location. Of these locations, 17 had been confirmed as SOMAs and 12 core areas were verified. Breeding pairs or fledglings had been observed in three of these SOMAs. Field work involved 2,627 hours, which was estimated to be one-third to one-half of the total expended on implementation of the SOMP.

By including all 48 known locations and all potential suitable habitat on one map, it was apparent that there were still some weak links in the geographical distribution of spotted owls and habitats on the Olympic's east and south sides. These were due primarily to previous fire history on the east side and intensive and extensive timber harvest on the south side. I had repeatedly expressed concern to the Regional Office biologists that the probability existed that spotted owls on the Olympic Peninsula were genetically isolated from those occurring in the Cascade Range, and that this isolation may have begun in the very early 1900's when the lowlands in the Puget Trough were logged off within a 30- to 40-year period. An analysis of the risk involved in managing 17 habitats for

spotted owls in the Olympic following the procedures of Salwasser<sup>3/</sup> indicated that this population, viewed in isolation, could become 50 percent inbred in only a few generations.

Recognizing that the Peninsula subpopulation of spotted owls included those on adjacent lands, the Olympic National Park was queried for any spotted owl use data and an estimate of the amount and location of potentially suitable habitat. Park personnel had very limited data and declined to make an estimate of habitat. I polled seven Forest Service and State biologists for an estimate of either spotted owl density or suitable habitat in the Park; estimates ranged from 42 to 109 pair. Risk analysis was again performed (including potential Park owls), which indicated long-term evolutionary fitness was unlikely for an isolated Olympic Peninsula subpopulation. Department of Game had data on three owl areas on adjacent Department of Natural Resources lands, but to date there has been no State agreement to manage spotted owl habitat.

Direction from the Regional Office was received in April and included recognition of the probable isolation of spotted owls on the Olympic Peninsula. It was suggested that, in the absence of protection for habitats linking the Olympic Peninsula and the Cascade Range, the Olympic subpopulation might be periodically enhanced through transplants in cooperation with Department of Game. Other direction stated that the number of SOMAs to be managed, at a minimum, would be determined by an appropriate distribution of habitats rather than by a number of owl pairs calculated to provide genetic viability.

The new distribution requirements were mapped and SOMAs located such that any one SOMA was distributed within dispersal distance of at least three others, and so that no large area was void of habitat. The Olympic, being too narrow to accommodate this distribution, and having all but one SOMA distributed at 6 miles because of the single-pair situation, added potential Park habitats to the 28 or 30 needed for distribution on National Forest lands. These Park habitats were added where necessary to tie Olympic lands, fragmented by other landowners or unsuitable habitats into one continuous distribution. Suitable Park lands were taken from a map generated by remote sensing data, which included age and elevational criteria; none of these habitats have yet been examined on the ground or inventoried for owls.

During the 1984 field season, funds were requested to census the prey base in the stagnated timber stands within verified SOMAs. During monitoring, spotted owls were located in all 11 SOMAs evaluated, thereby validating procedures used to inventory and confirm these areas. Owls

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<sup>3/</sup>Contribution to Forest Service Handbook, FSH, 2609.14, draft November 25, 1983, Chapter 5.7, Viable Population Risk Analysis, 34 p., by H. Salwasser.

appeared to be spending as much time outside designated SOMAs as within, however, and some owls could not be located in the SOMA until late August after the breeding season. This preliminary information indicates the state of our imperfect knowledge of spotted owl habitats and habitat use.

#### TIPS FOR NEW PROGRAMS

There are a few hints I can provide to those contemplating the start of a program to manage spotted owls, or perhaps any species about which relatively little is understood:

1. Count on a long-term project. Identify and try to secure funding and personnel for a commitment of several years.
2. Concentrate surveys early in the breeding season. Spotted owls appear most territorial (responsive) before their young have fledged.
3. Don't waste your time. Visiting "perfect" habitat more than three to five times in a season appears to be nonproductive, though it should be visited in consecutive seasons and during the winter before being abandoned.
4. Recognize that suitable habitat is that which is occupied by spotted owls, not that which meets a standardized definition. Establishing habitat management areas in a generalized distribution pattern, then checking them for use causes constant readjustment and wastes time. General survey should be followed by habitat analysis, then future surveys refined to reflect such data.
5. A crew on contract is easier to standardize and supervise. I found that, in the Olympic, the contract crew had a response rate per unit time spent of one response per 5 hours of survey; crews of various changing Forest Service personnel achieved one response per 9 hours of survey; and a combination of in-house personnel plus one-third volunteers produced one response per 21 hours of survey.
6. Lack of owl response does not necessarily indicate that owls aren't there. Responsiveness appears linked to the technique of the caller, weather, time of day and year, individual differences, number of times previously called, phase of the moon, and whether or not it's Thursday.
7. When managing a species at low population levels, where viability is a concern, supply the best habitat available. Marginal habitat may be only periodically occupied or may not be able to support a breeding pair plus young.
8. Avoid conflicting resource uses, such as timber harvest, within SOMAs even though more than sufficient habitat is available. Ongoing monitoring will continue to refine spotted owl habitat use, and at low population levels, use should define habitat.

#### FUTURE NEEDS

The Olympic has defined its needs for more information through participation in the cooperative SOMA monitoring study (Carey and Ruggiero 1985). Additionally, information is being gathered on specific habitat use by adult owls in stagnated timber stands to define the SOMA parameters for

these anomalous situations. It would also be prudent to examine the suitability of Park lands and conduct a survey of spotted owls in habitats that were selected to geographically ensure a continuous distribution throughout the owls' range. Managing owls near minimum population levels allows little margin for error; assumptions regarding suitability and occupancy of several habitats imposes a very high risk.

Several years of observation and preliminary monitoring data indicate a need for more specific information regarding differences in "winter range" vs. "summer range" use by owls, differences in male vs. female use of the home range during non-breeding years, home range size of fragmented SOMAs vs. contiguous ones, reproductive strategy, and fledgling survival. These require research efforts beyond the scope of an individual Forest to pursue.

Finally, there is a continuing and future need for flexibility in management direction. Direction and guidelines need to be more immediately responsive to new or site-specific data in order for habitat to be managed to maintain pairs of spotted owls. Presently, habitats are assigned to owls and they must fit within those or perish. With continuing monitoring and refinement of data on habitat use and spotted owl biology, the opportunity exists to manage habitats selected by the owls.

#### SUMMARY

Information on spotted owl distribution, density, biology, and habitat use has been collected in the State of Washington for only a few years. Imperfect knowledge coupled with the commitment to maintain viable populations of this species, considered threatened in the State, caused the Regional Forester to adopt habitat management guidelines and issue direction for implementation of the SOMP. This direction has been revised or refined nearly annually since 1977, but throughout, has been highly specific and based on research conducted, largely, in the forests of western Oregon.

Implementation of management guidelines and direction was accomplished through the coordinated, interactive efforts of personnel from many resource disciplines at both the Supervisor's and Ranger District offices. Though significant progress has been made in identifying the distribution, abundance, and habitats of spotted owls in the Olympic, implementation of the SOMP was made complex due to the peculiar geography of the Peninsula, the vagaries of spotted owl behavior, and other resource conflicts.

The Olympic is committed to more complete, site-specific knowledge of spotted owl habitat use and continues to gather data through monitoring and administrative studies. The expectation is that management direction in the future will be flexible and responsible to new information, for after all,

The ultimate result must be that we maintain viable populations of spotted owls, over time, such that we prevent the need for Federal listing.

R. E. Worthington  
Regional Forester  
October 28, 1980

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## MANAGEMENT OF SPOTTED OWLS BY THE CALIFORNIA DEPARTMENT OF FISH AND GAME

Gordon I. Gould, Jr.

**ABSTRACT:** The California Department of Fish and Game must maintain populations of spotted owls for the intrinsic and ecological values of the owls. The Department performs this job through a coordinated effort with land management agencies to protect the old-growth and mature forest habitat required by the owl. Commercial logging dramatically reduces this habitat and jeopardizes the species' existence. Problems in current land management planning are discussed and research needed to improve management is identified.

### INTRODUCTION

The California Department of Fish and Game (CDF&G) is charged with the conservation of all wildlife within the State, including species that are not harvested (Section 1801, Fish and Game Code). This specific legislative mandate calls for maintaining all species of wildlife and their habitat (1) for the use and enjoyment by all citizens of the state; (2) for the intrinsic and ecological values that all species have; and (3) for aesthetic, educational and other nonconsumptive uses. Management for species that are not used consumptively (15 species of owls and 622 species of other birds and mammals) centers around habitat preservation.

In 1970, the California legislature passed the Endangered Species Act, recognizing that destruction of wildlife habitat, reduction in the amounts of certain types of habitat, and severe modification of many natural environments were endangering many species, or subspecies, of native wildlife.

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Subsequently, CDF&G's management activities included monitoring populations, determining habitat requirements, preserving particular habitats, and assessing other land management agencies in their management of land and other resources to preserve habitat and to maintain or restore population levels of particular wildlife species.

In the process of surveying for the needs of endangered species, the spotted owl (*Strix occidentalis*) was identified as a species whose numbers were declining, possibly to the point of extirpation (Remsen 1978). The major reason for the decline was a reduction in old-growth and mature forest, the habitat the owls require. The purpose of this paper is to report on the status of the spotted owl in California and to discuss the ways in which the CDF&G is attempting to maintain this species and its habitat.

### CDF&G ACTIVITIES

The first activity the CDF&G participated in was a State-wide survey to determine the distribution and habitat requirements of spotted owls (Gould 1974). Present activities include: continuously monitoring populations of spotted owls to determine how constant the occupancy of territories

is, what the distribution of territories is across the State, and regional trends in populations; working with other government agencies to coordinate research on spotted owls, which includes the habitat requirements and the effects of land management on populations; compiling the results of research on owls and serving as a central source of information on the owl's status, biology, and management; assisting Federal, State, and private land managers in developing plans and guidelines that will preserve the habitat of spotted owls (Gould 1983); and reviewing plans for selling timber and timber harvests to ensure that the needs of spotted owls are considered.

#### CURRENT STATUS OF SPOTTED OWLS

The Department has classified the spotted owl as a "bird species of special concern." This designation carries no special legal status but only designates a species as one whose population has declined severely or is otherwise so low that extirpation is a real possibility.

Currently three geographically distinct populations that belong to two described subspecies are recognized (Grinnell and Miller 1944). The northern spotted owl (*S. o. caurina*) occurs from Marin County north along coastal California to the Oregon border and east to northeastern Shasta County. The California spotted owl (*S. o. occidentalis*) is found the length of the Sierra Nevada from southeastern Shasta County to northeastern Kern County; a second population occurs along California's south coast from Monterey County to San Diego County. The status of each population seems equally critical, although the nature of current threats vary.

Within this distribution there are 1,317 sites classified as territories (table 1) where (1) a pair has been observed; (2) young have been observed between May and September; or (3) a vocal defense of an area has been heard or solicited. However, this number doesn't represent the number of currently active sites as some sites have been abandoned and others may be yet undiscovered.

It's difficult to compare current densities of spotted owls with past densities. The lack of information on the distribution and density prior to 1973 can best be demonstrated by the State-wide estimate, made in 1971, of 30 pairs.<sup>†</sup> Therefore, I can only speculate about historical densities. Spotted owls have been reported from 549 different townships throughout California. Only one territory has been recorded for most townships. However, 6 to 11 territories have been recorded for 37 townships. Twenty-six of these townships are in north coast counties, 10 are in central Sierra Nevada counties, and only 2 are in south coast counties. Most of these areas are not pristine; I have personal knowledge of logging occurring in at least half of these townships, and logging probably has occurred in many of the others.

Table 1--Known distribution of spotted owl territories in California, June 1, 1984

County	Present number known	Nos. for northern spotted owls	Nos. for California spotted owls	
			Sierra Nevada	South coast
Alpine	3		3	
Amador	6		6	
Butte	19		19	
Calaveras	11		11	
Colusa	2	2		
Del Norte	41	41		
El Dorado	75		75	
Fresno	23		23	
Glenn	12	12		
Humboldt	117	117		
Kern	13		10	3
Lake	18	18		
Lassen	11		11	
Los Angeles	13			13
Madera	24		24	
Marin	18	18		
Mariposa	29		29	
Mendocino	38	38		
Modoc	1	1		
Mono	1		1	
Monterey	9			9
Napa	4	4		
Nevada	12		12	
Orange	2			2
Placer	40		40	
Plumas	83		83	
Riverside	4			4
San Bernardino	28			28
San Diego	21			21
San Luis	8			8
Obispo				
Santa Barbara	17			17
Shasta	36	22	14	
Sierra	27		27	
Siskiyou	250	250		
Sonoma	5	5		
Tehama	58	46	12	
Trinity	146	146		
Tulare	35		35	
Tuolumne	43		43	
Ventura	6			6
Yuba	8		8	
Totals	1317	720	486	111

One could infer that densities of five territories of spotted owls per township probably were not uncommon historically. Using a conservative historical density of 3.5, or 32 percent of the currently known maximum density, provides an estimate of the spotted owl population that existed in pristine times at almost 2,100 territories. This assumes that current distribution and historical distribution are the same and that historical density was 1.6 times current density.

<sup>†</sup> Personal communication, Ned Johnson, University of California, Berkeley.



ere is good evidence that historical distribution was more extensive than the current distribution. Spotted owls are no longer present at at least 30 of approximately 125 historical sites (Gould 1974). This implies that the minimum historical range of spotted owls included at least 105 more territories than calculated above.

Population trends can be implied both from trends in the density of owls and from trends in the numbers of territories over a period of time. The trend of a reduction of density and range that was calculated above shows a reduction of at least 50 percent. Other evidence of a decrease in spotted owls was gathered in a survey in 1974; spotted owls were present at only 73 percent of the previously reported occupied sites (Gould 1974). Because the time between the first sighting and the most recent sighting varied, it was impossible to determine the rate of loss. However, over the last 10 years the Department has monitored 1,317 territories; at the last visit, 58 of these sites were not occupied. It's possible that spotted owls were present but not detected or that the site was of marginal quality to begin with and isn't consistently occupied. I calculate that 1,259 of the 1,317 territories are presently occupied--a reduction of 4.5 percent over 10 years. This population size probably is smaller because those territories with the highest disappearance rate are those where only one report has been received for that territory and that report was of a single individual. Of the 1,259 occupied territories, 407 of these are single sightings of individual owls; pairs have been verified at only 41.6 percent of the territories.

As the number of territories increases the chance of adding new territories decreases. The USDA Forest Service has intensively surveyed 10 of the 17 National Forests in California; four other forests have been lightly surveyed. Surveys have covered from 50 to 85 percent of Forest Service lands, with most areas about 75 percent surveyed. Other lands were not as well surveyed; but these lands probably don't provide habitat for many spotted owls.

The California Region (Region 5) of the Forest Service controls 19,680,327 acres of land (USDA Forest Service 1979), much of it forested. Additional land is controlled by the Bureau of Land Management, but much less is forested. Large quantities of privately owned forest land exist but were the first areas logged; suitable owl habitat (old-growth and mature forest) is now scarce. Forests also occur in some State and Federal parks. On these lands, timber harvest does not occur and old-growth and mature forest habitat is usually the management objective.

More spotted owls are found on Forest Service land than on that in any other ownership (table 2) (Gould 1979); this clearly demonstrates the importance of Forest Service land to the preservation of this species in California. Currently, this land is being logged. It has been estimated that all commercially suitable old-growth forest habitat will be cut within 25 years. This

logging will reduce owl habitat and spotted owl populations; it is doubtful that viable populations of this species will be maintained unless some accommodations are made. Similar logging is occurring on BLM and privately owned timber lands with few or no restraints to protect spotted owls.

Table 2--Land ownership of spotted owl territories in California, 1978

Ownership pattern	Percent territories by subspecies		Total percent
	Northern	California	
Completely private	4.5	4.0	4.2
Private near	1.5	10.9	6.2
Federal land			
Completely	40.6	44.6	42.6
Forest Service			
Forest Service	31.2	26.2	28.7
with private land nearby			
Bur. of Land Mgmt.	5.4	1.0	3.2
with private land nearby			
Jointly owned by	2.5	4.5	3.5
Federal agencies			
Completely National	3.0	5.9	4.5
Park Service			
NPS with private land nearby	2.5	0	1.2
Completely State park land	0.5	2.0	1.2
State park land with private land nearby	6.4	1.0	3.7
Other	2.0	0	1.0

The preference of spotted owls for old-growth habitat has been well documented (Forsman 1976, 1980; Forsman and others 1977; Gould 1974; Marcot 1978; Marcot and Gardetto 1980; Solis and Gutiérrez 1982).<sup>2</sup> Old growth functions as the thermal cover necessary for the owl's survival (Barrows 1980, 1981; Barrows and Barrows 1978). The general biology and seasonal habitat use of the northern spotted owl has been described (Forsman 1976, 1980; Solis and Gutiérrez 1982). Ongoing research is documenting the winter habitat use of the northern spotted owls and the dispersal of young.<sup>3</sup> Also, year-round habitat use, occupation patterns, and the dispersal of young are being studied in a central Sierra Nevada population of the California spotted owl.<sup>4</sup>

<sup>2</sup> Unpublished Progress Report, 1981, "Habitat use by radio-tagged northern spotted owls on the Six Rivers National Forest," by David M. Solis, Jr., and Chuck Sisco, Six Rivers National Forest, Eureka, CA.

<sup>3</sup> Personal communication, Chuck Sisco and Ralph Gutiérrez, Wildlife Department, Humboldt State University, Arcata, CA.

<sup>4</sup> Personal communication, Stephen Laymon, School of Natural Resources, University of California, Berkeley.



## COORDINATION IN LAND MANAGEMENT

The Department has collaborated with the USDA Forest Service and the State Board of Forestry in an effort to manage spotted owls. Both efforts involved trying to establish land management plans and regulations.

In 1983, under the California Forest Practices Act, the Board of Forestry listed species that must be considered in the planning of timber sales on private land. This list contains the species designated as "rare" or "endangered" by California or designated as a species of special concern by the Board. The Department made recommendations to the Board for establishing the list of species and the timber management activities that should be required to protect these species. The Department also acted in an advisory capacity to the Board in their deliberations. The Board didn't list the spotted owl as a species of concern because of a lack of information, and because of the large territory size and the amount of potential timber that might be tied up by any single spotted owl territory.

Collaboration with the Forest Service at the field level has involved input and comment on individual timber sale plans by Department biologists. These area biologists review proposed sales and comment on the effects of the proposed sale on wildlife resources and suggest mitigation or alternatives to reduce the impact.

At the staff level, collaboration has involved the exchange of survey and research data, establishment of guidelines for spotted owl management, and the review of individual forest plans to determine if these plans comply with the guidelines. To date, 36 surveys have been performed by individual forests or ranger districts. These surveys have provided more records of spotted owls than has any other survey effort.

In 1981, the Department assisted the Pacific Northwest Region (Region 6, Portland) of the Forest Service by participating in a workshop assessing regional spotted owl management guidelines. Similar assistance was given to the Pacific Southwest Region (Region 5, San Francisco).

The Department has a representative on the Forest Service's regional review team (Region 5) that evaluates the land management plan for each forest. Both Department staff and area biologists review and comment on the wildlife portion of each forest plan. Spotted owls are a major concern in the Department's review of these plans.

## IMPROVEMENTS NEEDED IN COLLABORATIVE EFFORTS

The Department is a single purpose agency and precise agreement with other agencies and private groups on land management decisions is not always possible. This is especially true when dealing with agencies that are either single purpose or have a very dominant purpose that is not compatible with the complete maintenance of the wildlife resource.

Because of conflicts in resource use, compromises often must be made. With compromises wildlife always loses something. In the case of the spotted owl, compromise results in a decrease in available habitat and in putting the species in an ever more precarious position. Under such circumstances it is difficult to achieve the State's objectives of maintaining intrinsic and ecological values, providing use and enjoyment to the citizens of California, and maintaining aesthetic, educational, and nonappropriative uses. There must be limits to compromise once the resource no longer adequately provides these attributes.

There are several problems concerning spotted owls that result when land management agency objectives don't fully coincide with wildlife resource objectives:

1. The State Board of Forestry didn't designate the spotted owl as a species of concern. As a result it lacks the protection that it and many other old-growth forest species need on private lands. Spotted owls are among the best indicators of old-growth forest quality still found in the state's forests.

2. Although the Forest Service considers spotted owls in their land management planning effort, the plans, their guidelines and the manner in which they are being implemented may not offer adequate protection to maintain viable populations throughout California. More specifically:

- a. The planning process is biased towards the timber resource so that the preservation of other resources is jeopardized regardless of what alternative is chosen (CHEC 1984).<sup>5</sup>

- b. The plans are supposed to maintain a viable population of spotted owls but much of the information needed to determine what constitutes a viable population hasn't been gathered.

- c. There is no level of viability (probability of species survival) set in the planning process. Since a viable population level is not fixed through time,<sup>6</sup> the level of viability set in the management plans must accommodate the worst possible situation; the plans don't make this accommodation.

- d. An inordinate delay is occurring between the establishment of guidelines, the development of plans, and the implementation. Because the harvest of old-growth forests is

<sup>5</sup> Correspondence, H. E. Hodgdon, The Wildlife Society, letter of 4/9/84 to T. E. Hamilton, Director, RPA, U.S.D.A. Forest Service, Bethesda, MD, 5 p.

<sup>6</sup> Unpublished Administration Report, 1983, "Wildlife population viability--a question of risk," by Hal Salwasser and Stephen P. Mealey, USDA Forest Service, Pacific Southwest Region, San Francisco, CA.

continuing, it is likely that the plans will not be able to be implemented as written and planning guidelines will not be met.

3. The Bureau of Land Management, National Park Service, California State Board of Forestry, California Department of Parks and Recreation, and California Department of Forestry do not have any State-wide, long-term planning efforts that consider spotted owls.

The Department also needs to develop a plan for preserving old-growth and mature forest ecosystems. It has already done this type of planning for coastal wetlands. A plan for old growth forests should include an inventory of the remaining old growth, a list of species that must be accommodated in forest preservation, a description of the current and the desired status of the forest wildlife in California, and procedures for working with land management agencies to carry out the plan. To be effective, the plan must be implemented promptly because all the commercially available old-growth forest may be harvested within 25 years, and the sales for those harvests are likely to be planned within the next 10 years.

#### INFORMATION NEEDS

It's obvious that the multiple use of forests can't stop for spotted owls. But, the Department must demand, and other land management agencies must provide for, the preservation of all species throughout their ranges at ecologically sound population levels.

A species can't be preserved throughout its range without adequate surveys to delimit the range and to show patterns of abundance within the range. Surveys of habitat facilitate the population surveys, provide information on the potential range of the species, and the future potential area available for the species. Survey work isn't complete in the species' believed range in California. However, in many areas, particularly in a few National Forests, it is nearly complete.

The most important information that's needed concerns the population dynamics of spotted owls. Data is needed to prepare a life table for a viable population of owls; specifically needed are age-specific reproductive rates, age at first breeding, mortality causes, and age-specific mortality rates. This information could be used to model the normal functioning of spotted owl populations and to predict the population's ability to reproduce itself and sustain the population. What is required to sustain the population could be compared to what occurs under different regimes of habitat disturbance and distribution patterns. The future course of any subpopulation could be estimated and changes in population size and distribution could be predicted. Only then can land management plans be made that would provide a solid basis for maintaining viable populations.

Finally, the pattern of site occupancy must be studied to understand and determine the causes and rates of local extinctions and recolonizations. An extensive monitoring system would have to be established throughout the species' range to collect this information.

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STATUS OF SPOTTED OWL MANAGEMENT IN OREGON AS PERCEIVED  
BY OREGON DEPARTMENT OF FISH AND WILDLIFE

Richard D. Carleson and William I. Haight

**ABSTRACT:** The Oregon Department of Fish and Wildlife has a legal mandate to prevent serious depletion of wildlife species indigenous to Oregon. Because the population of spotted owls appeared to be threatened by timber harvesting, the Department took the lead in organizing an interagency wildlife committee. The committee, composed of representatives of land and wildlife management agencies, developed a Spotted Owl Management Plan. The plan calls for maintaining a minimum of 400 pairs of spotted owls in Oregon; the present population is 1,000-1,200 pairs. But cooperation and coordination among the land management agencies must be increased to accomplish this plan. And many questions, such as what constitutes a viable population, need to be answered.

INTRODUCTION

We estimate the present population of spotted owls (*Strix occidentalis*) in Oregon to be 1,000-1,200 pairs based on recent research by Forsman and others (1984). The Spotted Owl Management Plan recommended by the Oregon-Washington Interagency Wildlife Committee calls for maintaining 400 pairs in Oregon. Comparing the two numbers, it appears that the present population is high enough to maintain a viable population of spotted owls throughout most of their range in Oregon if sufficient habitat can be retained.

SPOTTED OWLS ON BLM AND PRIVATE LAND

Although the present statewide population is around 1,000-1,200 pairs, there probably is not sufficient habitat to support that number, even in the short term. Timber harvest patterns have incrementally nibbled away at what were once vast acreages of old growth, creating a high interspersed of clearcutting with old growth in some ownerships, particularly the checkerboards of private and Bureau of Land Management (BLM) lands in western Oregon. There the remaining old growth is highly fragmented with few 1,000-acre blocks of good spotted owl habitat. The gross acreage of old growth remaining in western Oregon is high enough to give the mistaken impression that there is plenty of habitat available. The fragmented habitat appears to allow existing spotted owls to survive in the short term, it is unclear whether they will be able to reproduce well enough to persist

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indefinitely. For example, 16 Spotted Owl Management Areas (SOMA) on the Coos Bay BLM District were surveyed in 1984 and only eight were occupied by spotted owls. Only one pair produced offspring. Spotted owl habitat on private land is, for the most part, already gone. Most of the old-growth stands large enough to contribute to a comprehensive spotted owl management plan were already harvested or committed to timber harvest before the Spotted Owl Management Plan was written.

The BLM lands in western Oregon offer better promise of maintaining spotted owl habitat than on private lands. Although sections of BLM land alternate with sections of private lands, BLM land still contains spotted owls and old-growth forest.

Four out of five western Oregon BLM districts (Coos Bay, Salem, Eugene and Roseburg) completed ten-year timber management plans in 1983. Inventory data presented in the BLM impact statements showed the existing population of spotted owls to be 177 pairs: the timber management plans protect the habitat of 64 pairs for 10 years. The protective standards, however, maintain only 300 acres of old-growth forest per spotted owl pair. According to the environmental statement, only 17 of the 64 SOMAs meet the minimum standards of the Spotted Owl Management Plan (SOMP) recommended by the Oregon-Washington Interagency Wildlife Committee. Because the BLM plans were regarded by the Department to need better protection of spotted owls, the department and BLM signed a cooperative agreement to provide needed protection for at least the first five years of the plans. The cooperative agreement is described later in this paper.

#### SPOTTED OWLS ON FOREST SERVICE LANDS

The spotted owls on the National Forests have more potential for survival. The forests haven't been as extensively harvested as BLM lands, so bigger blocks of old-growth habitat remain. A desirable distribution of SOMAs may be difficult to obtain, because the Forest Service ownership is not continuous from border to border (north and south) in the Coast Range. The planning process for the Forest Service is only partly completed, but there seems to be acceptance of the need to protect the habitat for owl pairs in close compliance with Oregon's Spotted Owl Management Plan. The Forest Service was allocated 290 pairs out of the 400 pairs recommended as minimum to maintain a viable population in Oregon throughout their range.

#### ODFW And The Spotted Owl

The overriding statement directing the Oregon Department of Fish and Wildlife (ODFW) is in the Wildlife Policy (Oregon Revised Statutes 496.012) adopted by the Oregon legislature in 1973. The appropriate part of the law is as follows: "It is the policy of the State of Oregon that Wildlife shall be managed to provide the optimum recreational and aesthetic benefits for present and future generations of the citizens of this

state...maintain all species of wildlife at optimum levels and prevent the serious depletion of any indigenous species...". The law does not define what the "optimum levels" are, nor does it establish what constitutes "serious depletion". The statutes authorize the Governor to appoint a seven member Commission to develop and implement policies and programs of the State for the management of wildlife and to promulgate rules to carry out the provisions of the wildlife laws. The wildlife laws relate mostly to the management and use of wildlife species. Traditionally, management of the land and its value as habitat has been at the discretion of the landowner. The end result is that the Commission can, by rule, regulate the taking or molestation of a species but has only limited authority to regulate habitat management on the lands of others. The department does seek habitat protection through laws and regulatory mechanisms of other agencies such as the Oregon Forest Practices Act and National Forest Management Act. The Commission did pass an administrative rule prohibiting the taking of sensitive wildlife, including State-listed threatened and endangered wildlife, and all nongame birds except sparrows and starlings. The ODFW was given authority to manage nongame wildlife by the 1971 legislature. Prior to that time authority was limited to game mammals and gamefish. A chronology of ODFW actions concerning the spotted owl follows:

May 1973.--John W. McKean, Director, Oregon Game Commission, proposed that a professional task force be formed and that its initial emphasis be placed on the identification of habitat requirements for the northern spotted owl (S. occidentalis cauriana).

The Oregon Endangered Species Task Force was established and recommended the adoption of statewide guidelines by June 30, 1974. Protection of 300 acres around each known northern spotted owl location was recommended as an interim protective measure pending the completion of a management plan. At that time there was no information on the extent of acres used for forest by spotted owls. For this reason, the 300-acre guideline was adopted only as an interim measure to be altered, if necessary when additional data became available.

October 1974.--The Sikes Act, Public Law 93-452, became law and provided for the protection for fish and wildlife, "officially classified as threatened or endangered pursuant to Section Four of the Endangered Species Act of 1973 or considered to be threatened, rare, or endangered by the State agency."

January 1975.--The Oregon Wildlife Commission adopted a list of threatened and endangered wildlife in Oregon. The northern spotted owl was listed as a threatened species on the official State list. Federal land managers were expected to provide protection for those species under the Sikes Act.

In 1977 the Oregon Endangered Species Task Force was reorganized into the Oregon-Washington Interagency Wildlife Committee, a multiagency group



formed to coordinate the activities of wildlife and land management agencies. It appointed a Spotted Owl Subcommittee. At this time ODFW's previous role as being solely responsible for formulating a spotted owl management plan became a shared responsibility with the other agencies.

The Spotted Owl Subcommittee completed a Spotted Owl Management Plan in late 1977. Through the Wildlife Committee the plan was transmitted to concerned agency administrators for review and comment. The objective of the plan was "to maintain a population of at least 400 breeding pairs of northern spotted owls distributed throughout the known range in Oregon". The Bureau of Land Management accepted responsibility for the protection of 90 pairs; the USDA Forest Service, 290 pairs; and combined, state lands (Department of Forestry, Oregon Department of Fish and Wildlife, and Parks Division), county lands, Crater Lake National Park and private lands were to protect 20 pairs. Each SOMA was to be at least 1,200 acres in size and to include at least 300 acres of old-growth forest. The Forest Service and BLM both agreed to implement the SOMP on an interim basis.

In 1981, after telemetry research on spotted owls indicated that the SOMP might not protect enough old-growth habitat, the subcommittee revised the SOMP to increase the old growth in each SOMA to 1,000 acres.

March 1981.--In March 1981, the Oregon-Washington Interagency Wildlife Committee adopted the Spotted Owl Subcommittee's revision to the Oregon SOMP. Robert M. Stein, chairman of the committee, forwarded the revised SOMP to the Regional Forester, Pacific Northwest Region, USDA Forest Service; State Director, BLM; and the Oregon State Forester for use in forest land planning. Formal acknowledgement of the acceptability of these revisions was not forthcoming from the Bureau of Land Management or the Oregon Department of Forestry. The Forest Service agreed to incorporate the revised standard into its planning activities.

September 1982.--When the first of five BLM timber management plans was proposed in September 1982, the Oregon Fish and Wildlife Commission found the proposal to be in violation of Oregon's Wildlife Policy, the Federal Sikes Act, and the Oregon Coastal Management Plan. One of the deficiencies in the plan was that only 300 acres of old growth per SOMA were to be protected instead of the 1,000 acres called for in the Spotted Owl Management Plan.

October 1983.--In the summer of 1983 all five BLM Timber Management Plans were adopted by the Bureau with the additional deficiency that the number of spotted owl pairs to be protected was less than called for in the SOMP.

After a series of negotiations involving several agencies and media exposure, an agreement was reached between the ODFW and BLM. The BLM agreed to manage spotted owl habitat in accordance with the best available scientific information for a

period of 5 years and ODFW would not pursue a legal challenge to the timber management plans. The agreement will provide sufficient habitat protection in the interim, but long-term protection requires successful completion of present research and reevaluation of the SOMP and timber management plans at the end of the five year period. ODFW and the BLM are presently evaluating implementation of the agreement.

The distributional requirements of the spotted owls are as important as habitat quality and quantity, and we are in the process of coordinating the distribution of SOMAs between the USFS and BLM.

There are no ongoing discussions with private landowners about maintaining spotted owl habitat. Most private holdings have been harvested, are too small to make a habitat unit, or have not been inventoried for spotted owls. Further, the bulk of the SOMAs (380 out of 400) have been allocated to the most extensive land managers (BLM and Forest Service); it seems reasonable to first secure protection on those lands, and then try to fit the remaining 20 SOMAs into the distribution provided by federal lands.

State lands do hold some spotted owl habitat, but population inventories have not been made. State lands are managed by various State agencies each having differing legal mandates. The majority of State lands are managed for timber production by the Oregon Department of Forestry.

#### Needed Collaboration

Development of the Spotted Owl Management Plan provided a necessary tool for protection of spotted owl habitat. It was intended to give land managers a recipe for protection that, if implemented, would maintain a minimum viable spotted owl population throughout its native range in Oregon. The SOMP represents minimum standards and the responsibility for success of the plan depends on implementation of the plan by each of the major landowners. There needs to be more coordination among the agencies responsible for implementing the plan. The coordination is difficult because the agencies have differing schedules for completing their land use plans. The plans of one land manager will affect the outcome of the plans of another agency. To make certain that spotted owl habitat units are distributed properly there must be continuous discussion among the agencies. Since the Spotted Owl Subcommittee has become more active, the interagency coordination has improved. It is expected that continued coordination by members of the Spotted Owl Subcommittee will provide updated direction to the land management agencies

The Spotted Owl Management Plan is dynamic and needs to reflect new research findings. The Subcommittee is expected to continuously evaluate the SOMP to see that it is state-of-the-art and to monitor its implementation by land managers.



## INFORMATION NEEDS

Many papers end with the statement that more research is needed; this paper is no exception. More answers are needed and are needed soon to such questions as: What is needed to ensure the continued existence of spotted owls? Is the population in Oregon isolated from the one in Washington? If so, is there a potential link somewhere in the Columbia Gorge? Can old-growth habitat be successfully managed to provide timber and old-growth-dependent wildlife? Can spotted owl habitat be created? How much fragmentation of old-growth habitat can be tolerated within a SOMA? Does a fragmented SOMA need more acreage of old growth than an unfragmented SOMA, and if

so, how much? Some of the SOMAs being selected by land managers appear to be in marginal habitat; can the parameters of the SOMP be successfully applied to marginal habitat? The questions could go on and on. Unfortunately it is easier to find the questions than it is to find the money to fund the answers.

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MANAGING NORTHERN SPOTTED OWLS IN WASHINGTON:  
THE POSITION OF THE WASHINGTON DEPARTMENT OF GAME

Tom Juelson

**ABSTRACT:** The northern spotted owl is classified as threatened by the Washington Department of Game. The Department considers the Olympic Peninsula spotted owl population to be isolated from all others and considers the Washington Cascade Range population to be genetically isolated from Oregon spotted owls by the Columbia River. The principal responsibilities of the Department are to protect and improve wildlife habitat, and to preserve, protect, and perpetuate wild animals in the best interest of the people of Washington. The responsibility of the Department to spotted owls is implicit under these guidelines. The Department is involved in independent research as well as interagency cooperative research regarding the spotted owl. Further collaboration among agencies is needed, particularly in managing the Olympic Peninsula spotted owl population. There are additional research needs in reference to the spotted owl which should be addressed.

STATUS OF THE SPOTTED OWL

The Washington Department of Game has classified the northern spotted owl as a threatened species in Washington. The State's definition of "threatened" is the same as that of the U.S. Fish and Wildlife Service. This spotted owl classification is currently under review for a possible change to "endangered". The final decision on the status is pending completion of research in Washington.

Department biologists currently perceive the spotted owl population in Washington as divided into two gene pools. One exists on the Olympic Peninsula. These spotted owls are isolated from genetic interaction with others because of large expanses of water and nonforested areas. The habitat there is severely fragmented for the most part and in short supply. It may be too late to provide enough habitat on the Peninsula to support a viable population, and it is highly unlikely that a forested corridor will be established linking the Peninsula with the Cascade Range in Washington. Some biologists consider the long-term existence of this segment of the spotted owl population to be endangered by any criteria.

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The second spotted owl gene pool in Washington is in the Cascade Range. This range includes the wet-type forests of western Washington and the dry-type coniferous forests of the eastern slopes of the Cascades.

The Department believes the Washington Cascades spotted owl population may be genetically separated from the Oregon population by the Columbia River and by adjacent land use in the river valley. The Washington Cascades population is continuous with the British Columbia spotted owl population; however, current information indicates that the British Columbia segment of the population is probably very small.<sup>1/</sup> Management considerations for the Washington Cascades spotted owl population, along with members of that population in British Columbia, should be based on a viable population level separately derived for the geographic area north and west of the Columbia River. Department biologists do not believe a satisfactory viable population level has been determined.

#### DEPARTMENT OF GAME POLICY

The policy manual of the Washington Department of Game provides a "statement of purpose" for each administrative division within the agency. Two of these divisions share the principal responsibilities with regard to the northern spotted owl: the Habitat Management Division and the Wildlife Management Division. The goal of the Habitat Management Division is "to protect and improve land and water habitats to assure optimal numbers, diversity, and distribution of wildlife for the welfare of people of Washington State." The goal of the Wildlife Management Division is "to preserve, protect, and perpetuate wild animals and to provide optimum wildlife oriented recreation for citizens of Washington through management, surveys, and research of birds, mammals, reptiles, and amphibians and their habitat." The spotted owl is a native species of Washington and the responsibility of the Department toward management of this species is implicit in these two statements.

#### COLLABORATIVE EFFORTS

The Department initiated independent research on spotted owl ecology in 1981 (Allen and Brewer 1985) which has stimulated a number of cooperative efforts between state and federal agencies and interactions between state and private industry in Washington. The Department is cooperating with three National Forests in Washington in an administrative study of the effectiveness of spotted owl management areas (Carey and Ruggiero 1985). USDA Forest Service, Burlington Northern Railroad, Weyerhaeuser

Company, and USDI National Park Service personnel cooperated with the Department in completing a statewide spotted owl survey. Department biologists are interacting with USDA Forest Service district biologists on many aspects of spotted owl information sharing (for example, location information, home range data, and habitat data). Department personnel are negotiating with the Washington Department of Natural Resources regarding Natural Resources policy on spotted owl management. Department research biologists are cooperating with wildlife management biologists from British Columbia in setting up spotted owl censuses in British Columbia that are targeted for spring 1985. The Department is conducting radio-telemetry monitoring of spotted owls on two ranger districts for the USDA Forest Service. This work is funded by timber sale revenues (Knutson-Vandenberg Act funds).

#### ADDITIONAL COLLABORATION NEEDED

A generally acceptable determination of a viable population level for spotted owls in the Washington Cascade Range and in the British Columbia populations should be made through an interagency approach. The U.S. Fish and Wildlife Service should consider reviewing the spotted owl population on the Olympic Peninsula to see if it should be declared endangered. If it is, cooperative efforts should be initiated to develop and carry out a maintenance program of the current population level. The Oregon-Washington Interagency Wildlife Committee and its Spotted Owl Subcommittee are developing means for interagency collaboration.

#### INFORMATIONAL NEEDS

To complete the evaluation of the size and distribution of the Washington and British Columbia spotted owl populations, we need good data on the British Columbia population. Genetic research to determine the extent of inbreeding in current populations would further facilitate the evaluation of species status.

The effects of habitat fragmentation and the size and distribution of habitat blocks on population should be more clearly defined, particularly with regard to predation and interspecific competition.

An analysis of habitat use in dry-type coniferous forests is needed to define the limits of spotted owl range in eastern Washington. This is particularly important in deciding the location of Spotted Owl Management Areas in dry-type forests.

Additional information on the relationship between prey species and spotted owl habitat use is needed to assess the merits of alternative forest practices (that is, selective harvest).

<sup>1/</sup> Personal communication, D. Dunbar and D. Wilson, B.C. Fish and Wildlife Management, Parliament Bldg., Victoria V8V 1X5.



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## SPOTTED OWL MANAGEMENT: MEETING NFMA REQUIREMENTS THROUGH MONITORING

Andrew B. Carey and Leonard F. Ruggiero

**ABSTRACT:** In 1983, biologists from USDA Forest Service research, three National Forests in Washington, and the Washington Department of Game collaborated to design and implement an extensive program for monitoring the effectiveness of the management area system for spotted owls--a designated management indicator species and key vulnerable species. The program will evaluate the success of the management system as well as current standards and guidelines for management. This kind of collaborative effort may be the only practical way to effectively monitor a species that is possibly in jeopardy from the reduction of its habitat.

### INTRODUCTION

The USDA Forest Service is charged with the authority and responsibility for managing the National Forests. Accompanying papers (Beckstead 1985, Carrier 1985, Lee 1985, Ruediger 1985) relate the procedures used and the difficulties encountered in planning for and making decisions about northern spotted owls (*Strix occidentalis caurina*). What, then, are the risks of making such decisions with incomplete information? For the spotted owl, wrong decisions or unexpected results could place in jeopardy the subspecies' existence, lead to a change in its legal status (for

example, it could be placed on the Federal Endangered Species List), and incur stringent constraints on future forest management. Worse, the subspecies could be extirpated from much of its range. Both situations would be failures in meeting management objectives as well as legal requirements.

What can be done to reduce the risks associated with making decisions based on incomplete information? Conservative decisions--those that assume the worst case--can be made. Advice can be obtained from persons most knowledgeable about the species. Research can continue to produce new information. Most importantly, however, the effects of the decisions can be monitored to determine if the objectives and expected results are being attained. The purpose of this paper is to discuss monitoring and to describe a monitoring program recently implemented in the National Forests in Washington to determine how well the Spotted Owl Management Area (SOMA) system is working.

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## MONITORING

Monitoring is an integral part of modern management systems. It provides information on the quality and quantity of the products of management and on the degree of attainment of goals and objectives. Monitoring provides an evaluation of the reasonableness of objectives and the efficacy and suitability of the processes (management actions) used to achieve the objectives. And monitoring provides information for future management.

The USDA Forest Service has adopted a goal-oriented approach to its management of wildlife and fish (Nelson and others 1983). Now the National Forest System is developing monitoring systems that are in accordance with legal requirements and management needs. Carey (1983) and Verner (1983) provide examples of how monitoring systems might be developed and advice on experimental design and sampling considerations for monitoring. Legislative mandates for monitoring the attainment of goals and objectives of wildlife and fish management were reviewed by Salwasser and others (1983). The National Environmental Policy Act of 1969 (NEPA), the subsequent regulations formulated by the Council on Environmental Quality, and, later, Executive Orders provide the basis for most of the requirements for monitoring by Federal agencies.

The regulations stemming from the National Forest Management Act (MacCleery 1982) provide the most explicit direction for monitoring by the National Forest System. The regulations require that monitoring be "addressed" in both the regional guide and forest plan. "On a sample basis", monitoring is to periodically determine and evaluate the effects of management practices, how closely management standards and guidelines have been applied, and how well objectives have been met. An important "minimum specific management requirement" is to provide for adequate habitat to maintain viable populations of existing native vertebrate species and to ensure that habitat for management indicator species is maintained or improved to the degree consistent with the multiple-use objectives established in the forest plan. The population trends of management indicator species must be monitored and relationships to habitat changes determined. Monitoring of populations is to be done in cooperation with State fish and wildlife agencies, to the extent practicable.

The Pacific Northwest Region (R-6—the National Forests in Oregon and Washington) of the National Forest System lists the northern spotted owl as a management indicator species and as a "key vulnerable species"—a species possibly in jeopardy because of reductions in its limiting habitat.<sup>1/</sup> Thus, minimum management require-

ments (including monitoring) for management indicator species and for minimum viable populations apply to the spotted owl.

## SPOTTED OWL MANAGEMENT IN R-6

Detailed information on spotted owls in the Pacific Northwest was first collected in the 1970's. The owl's association with old-growth Douglas-fir forests was documented and declines in populations were noted. In 1973 an inter-agency committee of biologists from the USDA Forest Service, USDI Bureau of Land Management, USDI Fish and Wildlife Service, Oregon State University, and the Oregon Department of Fish and Wildlife drafted a management plan for spotted owls. Later, biologists from the Washington Department of Game (WDG) joined the committee. R-6 accepted the recommendations of the committee and subsequent revisions (Forsman and others 1982).

In 1983, R-6 minimum management requirements (see footnote 1) for each pair of spotted owls in a Spotted Owl Management Area (SOMA) were 1,000 acres of old-growth forest with 300 contiguous acres constituting a nest grove (core area) and 700 acres within 1.5 miles of the nest, in patches greater than 30 acres, constituting a foraging area. If 1,000 acres of old-growth were not available, the next oldest stands were to be substituted for the old growth. Each SOMA was to encompass the home ranges of at least three pairs of owls. Single-pair SOMAs were acceptable only to improve the geographic distribution of SOMAs or where remnant habitat existed. SOMAs of three or more pairs were to be less than 12 miles apart; the core areas of multipair SOMAs were to be separated by 1-3 miles. Single-pair SOMAs were to be less than 6 miles from other SOMAs (core center to core center). The National Forests, with the Bureau of Land Management, were to maintain SOMAs for 400 pairs of owls west of the Cascade Range crest in Oregon; the National Forests in Washington (west of the Cascade Range crest) were to provide sufficient SOMAs to maintain 108 pairs of owls.

Proposed SOMAs were located using owl distribution maps and habitat descriptions, and through coordination with other land uses. The distribution of spotted owls in the National Forests was determined by eliciting vocal responses from spotted owls by broadcasting tape recordings of owl calls at night from roads and trails in mature and old-growth forest (see Forsman 1983 for procedures). A SOMA was considered verified (established) when occupancy was determined by repeated nocturnal surveys or when immature owls were observed. In April 1984 the minimum management requirements for the spotted owl were expanded to reflect the most recent information on the biology of spotted owls (see the paper by Lee in this symposium).

The procedures used to choose and verify SOMAs had several weaknesses, especially when they were applied in the National Forests in Washington. First, most research on the spotted

<sup>1/</sup>Jeff M. Sirmon. 1983. Regional guidelines for incorporating minimum management requirements in forest planning. Written directive to Forest Supervisors, Region 6, National Forest System, on file at Pacific Northwest Region, P.O. Box 3623, Portland, OR.



owl's habitat requirements had been done in Oregon and was not specific to Washington. Second, nocturnal surveys do not precisely determine an owl's home range and may be misleading because owls often move towards the caller before responding. And third, few nestling or fledgling owls were seen by National Forest System biologists. For these three reasons, an extensive monitoring program for spotted owls in National Forests in western Washington was developed jointly in 1983 by Forest Service and WDG biologists. Andrew Carey and Len Ruggiero represented Forest Service research; Bill Ruediger, the Gifford Pinchot National Forest (NF); Dick Dearsley, the Mount Baker-Snoqualmie NF; Maureen Beckstead and Kelly Coon, the Olympic NF; and Harriet Allen and Larry Brewer, the WDG. Earlier, Eric Forsman (Oregon State University) and Rocky Gutiérrez (Humboldt State University) had provided the group with unpublished reports and technical advice. Funds to implement the monitoring in 1984 were provided by R-6 and the WDG. WDG personnel are conducting the monitoring with assistance from the personnel at the National Forests and under the guidance of the ad hoc committee of biologists listed above. Total costs for a 3-year program are estimated to be \$380,000.

#### MONITORING SOMAS IN WASHINGTON

##### Objectives

The ad hoc committee formulated 2 primary objectives and 14 secondary objectives for the monitoring.

Objective I: Determine if the SOMA system is working.--It is presently assumed by R-6 that each SOMA will provide the necessary habitat to maintain at least one pair of spotted owls. At least the following will be determined:

1. The proportion of SOMAs occupied by spotted owls.
2. The proportion of SOMAs occupied by one or more pairs (male and female) of spotted owls.
3. The proportion of SOMAs occupied by breeding pairs of spotted owls.
4. The average number of spotted owls (and owl pairs) per SOMA.

Objective II: Determine if current standards and guidelines are appropriate.--At a minimum, two aspects of current standards will be evaluated: size of SOMAs and characteristics of SOMAs. For evaluating size standards, the following will be determined:

5. The proportion of the SOMA being used by spotted owls.
6. The amount of areas adjacent to the SOMA being used by owls.
7. The home range of owls using SOMAs.
8. The home range of pairs of owls using SOMAs.

For evaluating characteristics, the following will be determined:

9. The age of stands used by owls in the SOMAs.
10. The proportion of time spent in old growth by the owls.
11. The proportion of time spent in young forests by the owls.
12. The habitat characteristics (canopy layers, diameter at breast height, abundance of snags, and others) of areas used by owls.
13. The habitat characteristics of areas not used by owls, but in or adjacent to the SOMAs.
14. The differences between used and unused areas.

##### Study Areas

Population objectives were 49 pairs of spotted owls for the Mount Baker-Snoqualmie NF, 42 pairs for the Gifford-Pinchot NF, and 17 pairs for the Olympic NF. Each Forest biologist provided us with a sequentially numbered list of SOMAs equal in number to that Forest's population objective. We used a random numbers table to select the SOMAs to be evaluated: 19 SOMAs were chosen for the Mount Baker-Snoqualmie NF, 17 for the Gifford-Pinchot NF, and 10 for the Olympic NF. A list of alternate SOMAs was also selected for each Forest in the event one or more SOMAs had to be eliminated from the sample.

##### Methods

Determination of occupancy.--Forest Service personnel have surveyed most of the SOMAs for spotted owls. Thus, for some SOMAs, the primary center of activity or core area is known. Because owls range widely and may travel far to respond to calls at night, the core areas and actual occupants of many other SOMAs are not well documented. WDG monitoring crews will determine occupancy each year for at least 3 years. When the core area is known, the crews will visit the SOMA during the day to locate the resident owls. Nocturnal surveys will be made throughout the other SOMAs. If no owls are found it will be assumed that the SOMA is unoccupied that year. If owls are observed, then the center of activity will be located and visited during the day. All surveys will be done from March to August. Up to seven daytime visits will be made to each SOMA. If owls can't be found on seven visits, the SOMA will be classified as unoccupied for that year. If owls are found, the number, age, and sex of the owls and their roosting and nesting trees will be noted. If only one owl is observed at a time, it will be assumed that the SOMA was not occupied by a pair. If a pair of owls is seen or if young owls are seen, it will be assumed that the SOMA was occupied by a pair of owls. Occupancy will be determined in each of 3 years.

Use and home range.--Ten occupied SOMAs were selected for evaluation. Resident owls were trapped in early spring (1984) and fitted with radio transmitters. Each owl is being monitored

through radiotelemetry at least 1 day per week and 1-3 nights per week throughout the year. Areas used for foraging, roosting, and nesting are being determined. Movements and use (activity) will be plotted on aerial photographs or orthophoto quadrangle maps. Altogether, the proportion of SOMA used, habitats used, and home range will be determined by season for 10-20 spotted owls.

Description of habitat.--A standard sampling procedure developed by the Old-Growth Forest Wildlife Habitat Program for analyzing wildlife habitat will be used to describe used and unused areas in, and adjacent to, the SOMAs, with use determined by radiotelemetry. Both vegetation and environmental structure will be described.

## Results

SOMA effectiveness will be measured by the following statistics: proportion of SOMAs occupied, proportion occupied by pairs, and number of owls per SOMA. Because the sampling (choice of stands) was random, average effectiveness will be calculated forestwide and statewide. Effectiveness will be evaluated as follows: if on the average (over 3 years) 41 of the 46 SOMAs were occupied by pairs and over the 3 years every SOMA surveyed was occupied by a pair in at least 1 year, it would be concluded that the SOMA system was working very well. The conclusion has an implicit assumption that adult owls have a life expectancy of more than 3 years, during which at least two young would be produced. But if 23 of the 46 SOMAs were occupied by pairs with 15 of 46 never occupied, then effectiveness would be low and adjustments such as replacing the 15 never used with new SOMAs) would be indicated.

Habitat descriptions will be compared to current standards and guidelines to test their appropriateness. These results could be used to assess, and, if necessary, adjust the kind and amount of land managed for spotted owls. It may be possible to contrast the areas used by single owls with the areas used by pairs. Thus, definitive information on the habitat required to maintain a population could be provided.

## Coordination

The results of the monitoring program will be augmented by research being done by the Old-Growth Forest Wildlife Habitat Program and the WDG. The Old-Growth Program is collecting detailed information on the prey of spotted owls, the structure and composition of young, mature, and old-growth forests, the reproductive attainment of adult spotted owls, and the dispersal of juvenile spotted owls. The WDG has been conducting a statewide inventory of spotted owls, relating spotted owl distribution to land use patterns, and studying adult owl habitat use and juvenile owl dispersal. By the third year of the monitoring program substantial new information relating to spotted owl management will be available.

## CONCLUSION

Federal regulations call for monitoring populations of management indicator species. Monitoring is a complex and costly procedure. In Washington, Forest Service research, three National Forests, the Pacific Northwest Region of the National Forest System, and the Washington Department of Game have collaborated in designing and implementing a program for monitoring the attainment of the Forest Service's objectives in managing for spotted owls and for evaluating the standards and guidelines to manage habitat for spotted owls. Such collaborative efforts have much promise and may be the only way to accomplish effective monitoring of key sensitive species. This monitoring system model is a prototype for all monitoring in the National Forest System; the level of investment, however, must be matched to significance of the land use issue for other species.<sup>2/</sup>

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AN OVERVIEW OF RECENT RESEARCH  
ON THE SPOTTED OWL

R. J. Gutiérrez

**ABSTRACT:** The recent literature on the northern spotted owl (Strix occidentalis caurina) is reviewed and the salient features of the owl's natural and life history are presented. The conclusion is that northern spotted owls are dependent upon old-growth conifer forests of the Pacific Northwest.

INTRODUCTION

The spotted owl (Strix occidentalis) occurs as three recognized subspecies (S. o. caurina, S. o. occidentalis, and S. o. lucida) distributed from southern British Columbia south into Mexico (American Ornithologists Union 1957). The northern spotted owl (S. o. caurina) is thought to be closely associated with old-growth Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco) forests throughout the Pacific Northwest (Forsman and others 1977, 1984; Gould 1974; Grinnell and Miller 1944; Gutiérrez and others 1984; Solis 1983). The importance of these forests to both the timber industry and the spotted owl is the center of a growing controversy over the disposition of old-growth forests and the future of the owl (Heinrichs 1983, 1984).

Spotted owls appear to be declining with the continued logging of old-growth forests (Forsman and others 1977, 1982, 1984; Gould 1977, 1985; U.S. Department of the Interior, Fish and Wildlife Service 1982). Most of the remaining old-growth areas occur in National Forests (Forsman and others 1984; Gould 1979, 1985). The National Forest Management Act of 1976 (U.S. Laws, Statutes,

etc. 1976), which requires maintenance of viable populations of vertebrate species on all National Forests, is being invoked as a reason for intensive investigation and management of spotted owls and other old-growth wildlife species (Carey 1984, Carrier and others in press, Gutiérrez and others 1984, Ruggiero and Carey 1984).

In this paper, I will summarize the recent research on northern spotted owls within the context of natural history and life history characteristics that are particularly important for the management of this species. Campbell and others (in press) have provided an extensive bibliography on the spotted owl. I will therefore not attempt to incorporate obscure agency reports unless they are particularly germane.

NATURAL HISTORY

General Comments

Prior to 1970, most observations and research on spotted owls had been anecdotal (Campbell and others in press), and the bird was thought to be rare and secretive. Forsman (1976, 1980) was the first to record extensive natural history observations of the spotted owl and to summarize usable field study techniques (Forsman 1983). His work was especially timely with passage of the National Forest Management Act of 1976. In the following natural history review I will first present information on vocal and morphological

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characteristics that have been found useful in spotted owl studies. Then I will summarize salient features of spotted owl habitat, home range and movements, and food habits.

#### Vocalizations

Spotted owls are territorial and actively defend their home range, particularly the nest grove (Forsman 1976, 1980; Forsman and others 1984). Thus, they can be located through imitation of their calls. Males can be distinguished from females by the male's lower-pitched, four-note hoot (see Forsman and others 1984 for a more complete description of the owl's vocal repertoire).

#### Molt and Sexual Characteristics

The molt of the spotted owl has been described by Forsman (1981). Of particular interest to biologists is the fact that three age classes can be distinguished: juveniles can be identified by the presence of downy plumage until about 3 months postfledging; immature/subadult birds can be distinguished by the presence of pointed, white-tipped middle rectrices from their first autumn of life until midsummer of their third year; and adults have rectrices with rounded tips. Barrows and others (1982) describe a method for determining the sex of spotted owls by retrix barring pattern. Miller and Meslow (1985) have reported this method to be accurate.

Females are, on the average, larger than males (Earhart and Johnson 1970); however, the overlap in weights, between large males and small females, does not allow sexual determination. Similarly, juveniles are usually at or near adult weight soon after they are able to fly (personal observation); thus weight cannot be used as a criterion for either age or sex determination. Tail-barring pattern may be the best future method for determining the sex of juveniles.

#### Habitat

Perhaps the most important contribution of recent work has been the analysis of habitat and home range (the latter will be discussed in the next section). This information has been critical to the delineation of appropriate habitat for Spotted Owl Management Areas (SOMAs in the Pacific Northwest Region, USDA Forest Service) and Spotted Owl Territories (SOTs in the Pacific Southwest Region).

Forsman and others (1984), Gutiérrez and others (1984), Sisco and Gutiérrez (1984) and Solis (1983) demonstrate a significant association of the owls with old-growth forests. Solis' work is particularly useful in that it describes not only an affinity for old growth, but also describes the forest structure in detail. Although Douglas-fir old growth is the most important habitat type, much old growth (and mature, unmanaged conifer forests) below the high elevation subalpine

conifers also is occupied by spotted owls (Forsman and others 1984, Solis 1983).

Several interesting features of habitat use are emerging from the studies. First, although spotted owls can be found within second-growth conifer forest, and in other habitats, it is unknown if they are reproductively successful; this aspect needs further research (Forsman and others 1977, 1984). Neither presence-absence nor abundance of owls alone should be used as an indicator of habitat quality (Van Horne 1983). Fitness, when measured as breeding success, should be used as one of the primary criteria for the quality of habitat (Van Horne 1983). Second, not all old-growth stands appear to be equally used by the owls<sup>1/</sup> (Solis 1983). Use may be related proximately to habitat structure per se, or ultimately to food resources (see also Hildén 1984 for a theoretical discussion of these concepts). Third, male and female owls appear to be using habitat of different structure (Sisco and Gutiérrez 1984, Solis 1983, see footnote 1).

In general, spotted owls use old-growth forests that are characterized by multistoried stands of large-diameter (> 91 cm in diameter at breast height [d.b.h.]) conifers with hardwood understories in northwestern California. In Oregon, the understory may be either hardwood or conifer (Forsman and others 1984, p. 16). The stands in California have high canopy closure (approximately 80-90 percent) and they are old (> 150 years) with a high degree of stand decadence (Sisco and Gutiérrez 1984, Solis 1983). Spotted owl habitat in Washington appears to closely resemble Cascade Oregon habitats but has 90 percent canopy closure (Garcia 1979).

Tables 1, 2, and 3 present data that more specifically define the owl's habitat in northwestern California. The multistoried pattern of spotted owl habitat is easily discerned from tabulation of tree density and basal area (table 1). Douglas-fir dominates the upper canopy and hardwoods the lower strata (that is, diameter classes). There are, however, conifers and hardwoods represented in all diameter classes.

A comparison of table 1 with table 2 shows the average age of trees in the largest diameter class ( $\geq$  91 cm d.b.h.) is 268 years; the tree diameter class 53-91 cm d.b.h. averaged 142 years. There is much variation in ages among trees of a particular size class as a result of the influence of site factors, elevation, and exposure. Table 3 indicates that these stands also have a high degree of decadence associated with them. Stands used by spotted owls in northwestern California may therefore contain relatively small diameter (53-91 cm d.b.h.) trees but exhibit properties of stands that are much older. Such properties include (1) a multiple canopy of hardwoods and

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<sup>1/</sup>Manuscript in preparation by David Solis, Wildlife Department, Humboldt State University, Arcata, CA 95521.

Table 1--Some tree characteristics within spotted owl habitat in northwestern California<sup>1/</sup>

Diameter size class <sup>2/</sup>	Mean density	Mean basal area
	stems/ha	m <sup>2</sup> /ha
Hardwoods:		
I	46.20	0.48
II	154.14	4.40
III	47.54	5.26
IV	9.80	3.27
V	1.26	1.30
Subtotal	258.96	14.71
Conifers:		
I	17.98	0.18
II	74.47	2.27
III	48.28	5.68
IV	25.67	9.81
V	27.57	35.74
Subtotal	193.99	53.70
(Douglas fir)	171.73	49.65
Total trees	452.95	68.41

Data from Solis (1983) and Sisco and Gutiérrez (1984) and represent 723 vegetation plots 0.02 ha in size.

Diameter size class: I = 10.16-12.44 cm d.b.h. (diameter at breast height); II = 12.7-27.68 cm d.b.h.; III = 27.94-53.08 cm d.b.h.; IV = 53.34-91.19 cm d.b.h.; V = >91.44 cm d.b.h.

Table 2--A sample of Douglas-fir (*Pseudotsuga menziesii*) tree ages within spotted owl habitat in northwestern California<sup>1/</sup>

Diameter size class <sup>2/</sup>	Mean	S.D.	Sample size
	years		
I	47.3	13.0	3
II	51.8	8.5	5
III	114.1	57.2	70
IV	142.0	65.3	84
V	268.66	108.3	86

<sup>1/</sup> Data is from Sisco and Gutiérrez 1984.

<sup>2/</sup> Diameter size class: I = 10.16-12.44 cm d.b.h. (diameter at breast height); II = 12.7-27.68 cm d.b.h.; III = 27.94-53.08 cm d.b.h.; IV = 53.34-91.19 cm d.b.h.; V = >91.44 cm d.b.h.

Table 3--Summer habitat characteristics of spotted owl habitat in northwestern California<sup>1/</sup>

Habitat characteristics	Summer
Snag density (stems/ha)	53.54
Canopy closure <sup>2/</sup>	87%
Decadence <sup>3/</sup>	
I	.28
II	.24
III	.48

<sup>1/</sup> Data are from Solis (1983) and Sisco and Gutiérrez (1984) and represent 723 vegetation plots, 0.02 ha in size.

<sup>2/</sup> Canopy closure is a measurement of both conifer and hardwood components of the stand.

<sup>3/</sup> Decadence: See Solis (1983) for a complete description of decadence; however, level III has highest snag incidence, indicating a more decadent stand.

conifers and (2) advanced decadence including dead and down debris and snags. Decadence plays a very important role in spotted owl habitat. First, suitable cavity nest sites are formed as a result of the decay and aging process. In addition, snags, decadent and rotting trees, and downed woody debris may provide cover and habitat for flying squirrels and wood rats, the spotted owl's major prey.

Removal of woody debris and understory vegetation may alter the foraging patterns of spotted owls. Solis (1983) reports that a radio-telemetered bird foraged within a shelterwood cut until the understory was burned as part of a silvicultural prescription. The owl was not observed to forage in this area after the prescribed burn until the understory vegetation had begun to grow again.

The pattern of habitat use in summer and in winter is similar (Forsman and others 1984, Sisco and Gutiérrez 1984). Winter habitats resemble summer habitat structurally (Sisco and Gutiérrez 1984) in spite of the large increases in winter home range area (Forsman and others 1984, Sisco and Gutiérrez 1984). Extensive analysis of plant species composition and structural analysis of northwestern California owl habitats is given by Sisco and Gutiérrez (1984) and Solis (1983). The old-growth habitat used by spotted owls are also the most valuable timber on public lands in the Pacific Northwest. One of the major questions that managers and biologists ask is whether the spotted owl is indeed dependent on old growth



(Carey 1984). There are several aspects of their habitat ecology that strongly indicate that spotted owls are dependent on old growth:

1. Habitat use patterns demonstrate the owl's association with old growth (Forsman and others 1984, Forsman and Meslow 1985, Gutiérrez and others 1984, Sisco and Gutiérrez 1984, Solis 1983; see footnote 1).
2. Spotted owl habitat characteristics demonstrate agreement between forest scientists and wildlife biologists that this habitat is classified as old growth (for example, Franklin and others 1981, Franklin and Spies 1984, and reference immediately above).
3. Habitat analysis demonstrates there is a statistical difference in forest structure between intensively used and available habitat (Solis 1983).
4. The decline of spotted owl populations as old growth is logged demonstrates an association between the owls and these particular forests (Forsman and others 1984, U.S. Department of the Interior, Fish and Wildlife Service 1982).
5. The correlation between home range size and the amount of old growth in the range demonstrates the importance of old growth in influencing home range size (Sisco and Gutiérrez 1984; see footnote 1).
6. Spotted owl behavioral response to heat stress by roosting in old growth demonstrates the importance of old growth for thermoregulation by owls (Barrows 1981).
7. The general absence of spotted owls on heavily cutover lands demonstrates a qualitative, negative impact on owl populations with loss of old growth (Forsman and others 1977).

#### Home Range and Movements

Adult northern spotted owls are considered sedentary animals (Forsman 1980, Forsman and others 1984, Sisco and Gutiérrez 1984, Solis 1983), even though some populations show migratory behavior (Laymon 1985). In contrast, juvenile spotted owls are highly mobile (Gutiérrez and others 1985, Miller and Meslow 1985).

Movements within the home range usually do not exceed 1.5 km (measured as straight distance from beginning to end of sample period) within a 24-hour period. Movements may, however, involve use of large areas (about 300 ha) within a relatively short period (3-4 weeks) (Forsman and others 1984; see footnote 1).

One interesting aspect of the home range is that it is large ( $\bar{x}$  = 785 ha in Sisco and Gutiérrez 1984;  $\bar{x}$  = 1713 ha, table 1, in Forsman and others 1984). Forsman and others (1984) state that an average of 131 days of observation was needed to determine 80 percent of an owl's home range area. The data from northwestern California probably

underestimate the home range size for most of owls radio tagged there because the monitoring period was less than 131 days. The owl's home range often increases substantially in size with winter range expansion (Forsman and others 1984, Gutiérrez and others 1984, Sisco and Gutiérrez 1984; see footnote 1). Home range size has been shown to be positively correlated with the amount of old growth within the range and not with other seral stages (see fig. 13 in Sisco and Gutiérrez 1984). Owls in fragmented forests sometimes have very large or very small home ranges relative to other owls (Forsman and others 1982, 1984; Gutiérrez and others 1984). Perhaps in the former case the owls use larger areas to encompass fragments of old growth (Forsman and others 1984, p. 54), and in the latter case they may be isolated by adjacent territorial owls or are constrained by inhospitable habitat (for example, clearcuts and grasslands) (see footnote 1).

The relationship among home range size, habitat dispersion, and habitat quality is still not well understood (Gutiérrez 1985). Owls in fragmented forests have limited access to old growth and may have reduced fitness (lower reproduction); this needs to be studied (Gutiérrez 1985). There is some indication that some owls with only limited old growth available to them have low reproductive output.<sup>2/</sup>

#### Food Habits

Although spotted owls capture a variety of prey, numerous food habit studies have shown that mammals are their major food resource--particularly flying squirrels, *Glaucomys sabrinus*, and woodrats, *Neotoma* sp. (Barrows 1980, 1985; Forsman and others 1984; Kertell 1977; Marshall 1942; Solis 1983). Earhart and Johnson (1970) suggest that spotted owls are more insectivorous than current data indicate. Forsman and others (1984) and Sisco<sup>3/</sup> believe that flying squirrels may predominate in the diet of owls living in mesic habitats and woodrats may predominate in more xeric environments. Habitat structure or food availability within these habitats may influence which prey species is most abundant. It is interesting that woodrats in northwestern California have a bimodal distribution of abundance; their greatest populations are found in early and late seral stage forests (that is, brushy clearcuts and old-growth forests) and the lowest populations are found in intermediate-age forests (Raphael and Barrett 1984).

Barrows (1985) presents data that suggest spotted owls may breed in years when their larger prey

<sup>2/</sup> Unpublished data by R. J. Gutiérrez and others on file, Wildlife Department, Humboldt State University, Arcata, CA 95521.

<sup>3/</sup> Manuscript in preparation by C. Sisco, Wildlife Department, Humboldt State University, Arcata, CA 95521.

either more abundant or more available. Barrows<sup>4</sup> has data on *Peromyscus* populations in his study area that suggest spotted owls do not appear to be tracking large *Peromyscus* populations. His idea is certainly plausible when one observes the large talons these birds possess. The large talons indicate evolutionary selection for handling large prey. The ecology of the spotted owl's major prey is not well understood but may ultimately be important in predicting reproductive biology and demography of the spotted owl (Gutiérrez 1985).

## LIFE HISTORY

Little is known of the demography or other life history characteristics of spotted owls. Studies of population dynamics require the construction of life tables. Although spotted owl demographic data are limited to first approximations, subject to modification with new information, life table construction is possible (Barrowclough and Coats 1985). In the following brief review I will describe those life history features that are particularly important to the demography of spotted owls.

### Reproductive Biology

There is substantial yearly and geographic variation in the proportion of an owl population that breeds (Barrows 1985, Forsman and others 1984, Gutiérrez and others 1984, Laymon 1985). Gutiérrez and others (1984) report general breeding failure throughout the Pacific Northwest. Forsman and others (1984), in analyzing 130 nesting attempts over 5 years, found on the average that 2 percent (range, 16-89 percent) of their pairs attempted to nest each year but Gutiérrez and others (see footnote 2) have noted a lower frequency of nesting attempts in northwestern California. They found an average of 36 percent (92 pairs (range, 0-45 percent) attempted to nest over a 3-year period. Some pairs appear to nest far more frequently than others; for example, Miller (1974) reports a pair (presumably the same birds) that nested in 5 of 7 years. Conversely, Barrows (see footnote 4) and Gutiérrez and others (see footnote 2) have monitored some nonnesting pairs for 5 years. These unsuccessful pairs were located in nonold-growth habitat or in fragmented habitat. Reproductively successful pairs may provide clues for isolating habitat quality or individual variation parameters responsible for that success. Yet Forsman and others (1977) correctly point out the need to study those few owls in second-growth forests (see also Gutiérrez 1985).

### Clutch Size

The modal clutch size was two in Forsman and others (1984). They refer to other historical

studies that report four-egg clutches although the maximum brood size (an index to clutch size) they observed was three. Forsman and others (1984) found no evidence for renesting by wild spotted owls, although captive birds have laid two clutches in one season (Forsman and others 1984). Because the birds are physiologically and genetically capable of laying two clutches, failure to renest may be related to food availability or some other factor.

Because males feed their incubating mates, females are dependent on the male's foraging ability (Forsman 1976). When foraging conditions are poor and the female is forced to leave the nest to search for food, the clutch may be lost. Poor food resources probably do not improve soon enough to allow a female to renest.

### Age At First Reproduction

Barrows (1985) reports a second-year female breeding and Miller<sup>5</sup> has observed a second-year female breeding. My field crew has also observed at least two second-year females paired with adult males. Because juveniles have a high mortality rate, second-year breeding, at least by females, may not be uncommon.

### Survivorship And Mortality

Juvenile owls have a low first-year survivorship (Forsman and others 1984, Gutiérrez and others 1985, Miller and Meslow 1985). Young *Strix* owls die for many documented reasons, such as avian predation, starvation, accidents, and human predation (Gutiérrez and others 1985, Southern 1970). Young spotted owls are especially vulnerable during development following fledging and during early dispersal (Forsman and others 1984, Gutiérrez and others 1985, Miller and Meslow 1985).

Forsman and others (1984) suggest that spotted owls are long lived. Data on adult demography will be slow in accumulating and will require extensive banding and monitoring to determine adult survival rates. Adults are susceptible to predation, starvation, disease, and accidents, but the influence of these forces on survival is unknown.

### Density

There are few published accounts of density estimations in the strict sense of the term (Burnham and others 1980). Forsman and others (1977) published an "index of density," and Marcot and Gardetto (1980) published nearest neighbor distances and other estimates

<sup>4</sup>Unpublished data by Cameron Barrows on file, North Coast Preserve, Banskomb, CA 95417.

<sup>5</sup>Manuscript in preparation by Gary Miller, Oregon Cooperative Wildlife Research Unit, Oregon State University, Corvallis, 97331.



of density. The assumptions and applications of nearest neighbor distance has been discussed by Clark and Evans (1954) and Poole (1974). This technique is unsuitable for demographic (density) analysis. Barrowclough and Coats (1985) approximate the density of spotted owls across all habitats to be  $0.037 \text{ owls/km}^2$  (based on calling surveys compiled by the California Fish and Game Department).

Population boundaries need to be delineated to arrive at some area suitable for census. I would predict spotted owl densities are likely to vary substantially with habitat quality and quantity. Forsman and others (1977) found spotted owls substantially more abundant (approximately 12 times, according to their index) in old growth than in second growth. One of my study areas of 10,000 ha has 22 owls and a nearby area with good census data has 12 owls in 20,000 ha. The latter area has undergone extensive logging.

#### Dispersal

Dispersal ecology has been the subject of recent intensive research (Gutiérrez and others 1985, Miller and Meslow 1985). Preliminary results show that juvenile spotted owls are aggressive dispersers capable of moving long distances. They appear to move directionally and rapidly (Gutiérrez and others 1985). It is unknown from published data whether this pattern is consistent with other areas (Allen and Brewer 1985, Miller and Meslow 1985). Observations of the 1984 cohort of juvenile spotted owls in northwestern California suggest that this pattern may not continue (see footnote 2). As dispersal data continue to accumulate, managers will gain a critical piece of information for spatially distributing spotted owl territories and calculating demographic parameters for spotted owls (Barrowclough and Coats 1985).

#### Other Life History Features

Some important parameters of life history evolution are almost entirely unknown for spotted owls but ultimately may play a role in predicting the effect of management plans on the owls. Some of these are their interspecific competitive ability, variation in parental care among pairs, environmental stability, and population genetics (see also Stearns 1976, 1977, for a discussion of life history characteristics).

#### HYPOTHESES ON DEPENDENCE ON OLD GROWTH

Recent research has led to some interesting hypotheses concerning the spotted owl's dependence on old-growth forests. These hypotheses are:

1. Nesting hypothesis,
2. Thermoregulation hypothesis,
3. Predation hypothesis,
4. Prey hypothesis, and
5. Adaptation hypothesis.

Carey (1985) discusses these hypotheses elsewhere in this symposium. I have combined his two hypotheses on prey under one category because they are often interrelated. The implications these hypotheses for management will be discussed as will their potential for explaining the evolutionary relationships of spotted owls and old-growth forests. It is undoubtedly a combination of factors that have led to the spotted owl's role or dependence on old-growth forests. I have, therefore, expanded and reinterpreted Carey's (1985) adaptation hypothesis.

#### Nesting Hypothesis

Spotted owls, like most other owls, do not construct their own nests (Burton 1973). They depend on the natural occurrence of suitable nesting sites within their habitat. The location, structure, and type of nesting sites used by spotted owls are typically found in old, decadent forests (Forsman and others 1984). They are generally high above the ground ( $\bar{x} = 27.3 \text{ m}$ ;  $\bar{x} = 24.3 \text{ m}$ ); in cavities or broken-top snags (64 percent; 92 percent); and in large diameter tree ( $\bar{x} = 135 \text{ cm d.b.h.}$ ;  $\bar{x} = 170 \text{ cm d.b.h.}$ ) (Forsman and others 1984 and LaHaye,<sup>6/</sup> respectively). Old-growth forests are often decadent and provide the greatest number of trees suitable for nesting sites. It is unlikely that the need for nesting sites is the evolutionary force behind the dependence of spotted owls in old-growth forests for the following reasons. First, spotted owls do nest in abandoned stick nests built by other birds and in accumulations of organic debris in the tree canopy. Forsman and others (1984) report 36 percent of their spotted owl nests were of debris or were nests of other species. Both of these conditions can occur in younger aged forests, although accumulations of organic debris probably occur more frequently in old-growth forests (Forsman and others 1984). Second, residual, decadent trees are often left behind after fires or other natural environmental perturbations. Yet, spotted owls apparently seldom use these residual old-growth trees in younger forests (only 6 percent of the nests found by Forsman and others 1984, p. 30, were in young forests with scattered residual trees). Finally, open-canopied hardwood stands within old-growth areas often provide presumably suitable structural nest sites but are rarely used by spotted owls (see footnote 6).

From a management perspective, nesting sites can probably be created through manipulation. Live trees can be topped or cavities created in several ways to create structurally suitable nesting sites (see footnote 6). One pair of owl has been observed to use an artificial cavity in the Six Rivers National Forest (personal observation). The tawny owl (*Strix aluco*) of Europe responds readily to artificial nest boxes

<sup>6/</sup>M.S. thesis in progress by W. LaHaye, Humboldt State University, Arcata, CA 95521.



Southern 1970). Nest boxes have been placed in old-growth forests in California by Forest Service biologists without success (personal observation). The sites chosen for box placement may have already had abundant or traditional nesting sites. For example, my research crew discovered an active owl nest within 150 m of a nest box after the box had been placed in an old-growth tree. Because this pair had successfully nested in 2 out of 4 years at the natural site, it was unlikely that they would abandon their traditional site for the artificial one. The successful placement and construction of nesting boxes will depend heavily on adequate models of nesting sites and nesting habitat (see footnote 6).

#### Thermoregulation Hypothesis

Barrows and Barrows (1978) and Barrows (1981) first quantified the relationships between roosting site microclimate and heat stress in spotted owls. Spotted owls choose cool and shady microclimates that provide relief from high ambient temperatures (Forsman 1976, Solis 1983).

Because natural selection has favored the evolution of a plumage that is adapted to withstand winter conditions (Barrows 1981, Barrows and Barrows 1978), it is possible that use of the cool microclimate, which multistoried old-growth forests provide, is the counterbalance to the plumage. There are, however, several natural history observations that suggest that even though selection for old-growth roosting sites may be an indication of dependency on old-growth forests, it probably does not explain the dependency on large tracts of old growth.

Ward<sup>7/</sup> analyzed microhabitat selection and behavioral positioning in response to variation in ambient temperatures. He concluded that the position an owl chooses within the foliage is as important as the selection of actual roosting habitat. Sisco and Gutiérrez (1984) demonstrate that the old-growth forests are still the most important habitats for spotted owls when heat is not a factor. Alternatively, old-growth forests may provide more protection from inclement weather and, thus, may be important for winter thermoregulation (Forsman and others 1984).

This hypothesis is important to management. Spotted owls need adequate thermal cover in all seasons. Many areas of potential spotted owl habitat may not provide relief from heat without old-growth. In some areas access to old-growth roosting sites may energetically constrain the owls to a finite distance from the roosting site. Because owls can and do select roosting sites in cool, moist, shaded canopies within canyons to relieve heat stress, they may have some alternative habitats to use. Also, the small patches (24 ha)

of old-growth forest required as a minimum patch size for spotted owl management areas in California will probably provide an adequate microclimate to relieve heat stress. Yet SOMAs and SOTs without old growth on south-facing slopes or in areas where alternative habitats are not located will probably not be used by spotted owls.

#### Predation Hypothesis

Great horned owls (Bubo virginianus) and goshawks (Accipiter gentilis) will prey on juvenile spotted owls (Forsman and others 1984, Gutiérrez and others 1985, Miller and Meslow 1985; see footnote 1). Presumably, spotted owls are more vulnerable in open habitats than in the forests. The many observations of juvenile spotted owls moving through open areas (that is, grasslands, savannas, clearcuts, and oak woodlands) (see Gutiérrez and others 1985) suggest that the potential for predation does not, in general, deter these birds from using open areas when they are juveniles. Forsman and others (1984, p. 54) suggest adult spotted owls may also be preyed upon by great horned owls. Yet great horned owls are found throughout the range of spotted owls and often occupy areas adjacent to or overlapping spotted owl home ranges with little predation occurring (personal observation). I have recorded spotted owls temporarily avoiding an area when a great horned owl vocally established its presence, but the birds again used the area at some later date. Thus predation has probably occurred opportunistically at low levels for adults and at higher levels among juvenile spotted owls. This predation pressure has probably not been strong enough to explain the spotted owl's association with old-growth forests.

From a management point of view, predation could become a serious factor. If great horned owls increase in response to forest fragmentation, then the opportunity for their preying upon spotted owls will increase.

#### Prey Hypothesis

I have chosen to combine the prey abundance and prey availability hypotheses of Carey (1985) and Forsman and others (1984) into one hypothesis because I believe the hypotheses are closely related.

Raphael and Barrett (1984) suggest a bimodal abundance distribution for wood rats in northwestern California. These rodents are plentiful in shrub-sapling stages and in older aged forests. Raphael and Barrett (1984) demonstrate an increase in relative abundance of wood rats with increasing age of old-growth stands. Thus the spotted owl's primary prey, in northwestern California, is more abundant as the forest increases in age.

The reason that owls do not forage in shrub-sapling habitats probably is the inability of the owls to hunt effectively in these densely vegetated habitats (Forsman and others 1984). Solis

<sup>7/</sup> Unpublished senior thesis by J. P. Ward on file, Department of Wildlife, Humboldt State University, Arcata, CA 95521.

(1983) and Sisco and Gutiérrez (1984) demonstrate significant differences in foraging habitat between male and female owls. The differences in the structure of foraging habitat is probably related to the wing loading of the birds. The smaller, more maneuverable males use denser forests. Differential habitat use by the sexes may reflect an avoidance of competition. These differences persist in winter when home ranges expand and the birds forage independently (Sisco and Gutiérrez 1984, see footnote 1). Because shrub-sapling stages are far more dense than habitats normally used by foraging owls, one might expect that the owls cannot maneuver well enough therein to effectively prey on wood rats. Although Raphael and Barrett (1984) did not adequately sample flying squirrels, these animals are rare in shrub-sapling stages and in pole-sized timber.

The ecology of wood rats and flying squirrels within Pacific Northwest forests is not well understood. If their populations fluctuate asynchronously, or by habitat type and age, then it would help explain not only the foraging of owls within large areas but also the owls' use of a variety of stands greater than 150 years of age.

Hildén (1965) points out that food is one of the ultimate factors in habitat selection of a species, not only because of short-term physiological maintenance but also because of reproductive needs. It is probably the interplay of abundance, availability, and distribution of the spotted owls food base that explains the birds historical dependence on large tracts of old-growth forests. As its habitat becomes increasingly fragmented, the bird's needs for thermoregulation, for nest sites, and to avoid predators and competitors will become more important factors in the population ecology of spotted owls.

The prey hypothesis is probably the most important hypothesis for managers because it may explain the spotted owl's use of large tracts of old-growth forest. If the owl's major prey is geographically variable in abundance, distribution, or availability, spotted owls may have to forage widely through the year to find adequate prey populations. Thus the increased energy needed to exploit habitat patches in a fragmented forest may negatively affect reproductive output. The interrelationship between prey, territory size, and foraging patterns needs to be investigated to predict the impact of habitat fragmentation on the species (see also Gutiérrez 1985).

#### Adaptation Hypothesis

Carey (1985) discusses this hypothesis, which proposes that spotted owls have coevolved with old-growth forest and thus are behaviorally or physiologically adapted to these forests. In reality, this hypothesis is a combination of all other hypotheses and unknown natural selection forces. I will expand this hypothesis differently than does Carey (1985).

Biologists could engage in endless discussion over the coevolution of spotted owls and old-growth

forests. Spotted owls may have even secondarily invaded old-growth forests although this is unlikely. Nevertheless, there is considerable data, just presented, that old-growth is important if not critical for thermoregulation, nesting, foraging. Although ecologists are currently engaged in serious debate concerning the nature of competition (Salt 1984), one potential factor in the relationship of old growth and spotted owl might have been the competitive relationship with the larger and more widespread and aggressive great horned owl. One potential way of avoiding competition is through differential habitat use.

Through time the spotted owl's success in using old growth may have favored adaptive response to old-growth habitation regardless of the original pressure to use old growth. Forest fragmentation in the Pacific Northwest may also favor the spread of a potential competitor in the barred owl (*Strix varia*) (Gutiérrez and others 1984, Taylor and Forsman 1976). The interaction of these closely related species is now being studied by Allen.<sup>8/</sup> Introducing competitors, as well as changing the nature of the environment spotted owls have shown strong adaptive response to, could have serious consequences for spotted owls. Studies of spotted owls and their reproduction under varying environmental conditions will help tremendously in understanding the nature of the spotted owl's adaptability in a changing world.

#### CONCLUSIONS

Wildlife biologists have gained a great deal more information on the natural history than on the demography of the northern spotted owl. There are several reasons for this. First, natural history data are needed to establish a research foundation; second, natural history features are more easily observed in nature and often require only direct observation; third, natural history information provides the manager with the raw data for management (for example, habitat requirements and nest site selection). Life history characteristics provide the manager with the tools necessary for developing predictions of population viability. Many life history features, particularly demographic and, to a lesser extent dispersal information, take a great deal of time, energy, and money to quantify. Barrowclough and Coats (1985) and Shaffer (1985) point out the importance of this information for predicting the long-term viability of spotted owls. The need for specific research is outlined elsewhere in this symposium by Gutiérrez (1985).

Old-growth forests provide the food and cover essential for the survival and breeding success of northern spotted owls. The impact of habitat loss through logging over time must be assessed

<sup>8/</sup>—Manuscript in preparation by H. Allen, Washington Department of Game, 600 North Capitol Way, Olympia, WA 98504.



th in terms of natural and life history characteristics. Clearly habitats with known, nsistently reproductive pairs must be chosen as e SOMA. The ultimate numbers of owls to be intained will depend upon demographic and psersal information that is, at present, lacking. rst order approximations are possible (Barrow- ough and Coats 1984) but will undoubtedly change our understanding of the spotted owl increases.

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## BREEDING SUCCESS RELATIVE TO FLUCTUATIONS IN DIET FOR SPOTTED OWLS IN CALIFORNIA

Cameron W. Barrows

**ABSTRACT:** This paper describes infrequent, successful breeding in spotted owls (*Strix occidentalis*) and the relationship between breeding and diet. When spotted owls do breed, large prey such as dusky-footed woodrats and flying squirrels are predominate in their diet. The availability of these large prey items may be important in the breeding frequency and success of spotted owls. The relationship between breeding success and prey populations should be considered in the development and implementation of habitat-suitability models for spotted owls.

### INTRODUCTION

Recently there has been a substantial growth in the knowledge of spotted owl (*Strix occidentalis*) habitat requirements. Forsman's work in Oregon (Forsman 1976, 1980) provides an initial foundation for spotted owl research. For northern California, Solis (1983) and Sisco and Gutiérrez (1984) provide detailed analyses of seasonal habitat use by spotted owls. Barrows and Barrows (1978) and Barrows (1981) describe microhabitat selection related to the owls' thermoregulatory constraints.

Data from the studies mentioned above have been incorporated into spotted owl management plans by the USDA Forest Service and used to develop habitat suitability models (Laymon and Barrett 1982). There remains a serious void in knowledge about spotted owl habitat that precludes a well-informed application of these plans and models. For example, the factors that influence the reproductive success of spotted owls are poorly understood. Forsman (1976) first described the irregular breeding of spotted owls. Although

Barrows (1980) alludes to mechanisms responsible for breeding irregularity in spotted owls, the causative factors are not documented.

In this paper, I present results of a study designed to examine the causes of the lack of successful breeding in spotted owls. It should be noted that this is a multifaceted problem and only one aspect is examined here.

Newton (1979) has shown that breeding rates in raptors are positively correlated with food supply. Most studies examining this relationship have dealt with relatively simple predator-prey systems consisting of a single primary prey source (Adamick and others 1978, Hamerstrom 1979, Pitelka and others 1955, Smith and others 1981). Spotted owls take a broad spectrum of prey (Barrows 1980); any one of four major mammalian prey species can be the most prevalent in the owls' diet in a given year. My analysis examined the relationship between fledgling success and the relative frequency of these mammalian prey species in the diet of spotted owls.

### METHODS AND STUDY AREA

I collected regurgitated pellets below diurnal roost sites of spotted owls during 1977 through 1984. The pellets contained approximately 1,500 individual prey items. To facilitate comparisons over much of the spotted owls' range in

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California, I categorized prey species into two size groups: small prey -- animals that weigh less than 100 g, and large prey -- animals that weigh 100 g or more. Only mammalian prey were considered in this grouped analysis because mammals comprise over 90 percent of the biomass consumed by spotted owls (Barrows 1980). I also calculated mean prey weight of all prey species for each of my study areas.

For this study, I defined fledging success as the percent of occupied territories in each area in which spotted owl pairs fledged young over the 8-year period. Each year I observed owls in a territory was designated a potential breeding attempt. I recorded 47 breeding attempts in 21 spotted owl territories. Five of these territories were found in the Peninsular Range of southern California; the other 16 territories were located in Marin, Mendocino, Humboldt and Trinity Counties of northern California. My largest sample came from three occupied territories observed for 4, 6, and 7 years (17 breeding attempts) in The Nature Conservancy's northern California Coast Range Preserve in Mendocino County.

## RESULTS AND DISCUSSION

Forsman and others (1984) record spotted owl fledging success for Oregon over a 5-year period (1972-1976). They observed 130 breeding attempts with a fledging success of 44 percent. My data from California were similar with 47 breeding attempts over 8 years and a fledging success of 5 percent. Individual territories varied considerably in fledging success. Three territories in northern Mendocino County had a fledging success of 0 percent, 33 percent, and 29 percent, for 4, 6, and 7 years, respectively. One territory in central Humboldt County had a fledging success of 100 percent based on 6 years of observation. Barrett and Laymon (1982, 1983) report a fledging success of 6 percent based on 12 breeding attempts over 2 years in the Sierra Nevada of California. Miller (1974) reported a fledging success of 80 percent in 5 years of observation of one territory in Marin County, California.

The generally low and variable fledging success of spotted owls shows marked yearly trends. A broad regional failure in spotted owl breeding success was observed in 1982 (Gutiérrez and others 1983). Fledging success approached 0 percent for Oregon (Miller and Meslow 1984) and northern California.<sup>1/</sup> Breeding success improved in 1983. Of 63 occupied territories checked in Oregon, 48 percent successfully fledged young; on those territories with known pairs of owls, 62 percent successfully fledged young (Miller and Meslow 1984). In northern California in 1983, 17 percent of 87 occupied spotted owl territories successfully

Table 1--Percent occurrence of prey species in regurgitated pellets of spotted owls, collected from two owl territories in California

AREA/PREY SPECIES	1977	1980	1981	1982	1983
- - - - Percent - - - - -					
Northern Coast Range A <sup>1/</sup>	*				
<u>Neotoma fuscipes</u>	43	14	8	16	
<u>Glaucornys sabrinus</u>	17	8	3	32	
<u>Arborimus longicaudus</u>	9	35	50	32	
<u>Peromyscus maniculatus</u>	9	20	26	8	
Other mammalian prey <sup>2/</sup>	1	3	0	1	
Nonmammalian prey <sup>3/</sup>	21	20	13	11	
Northern Coast Range B	*				
<u>Neotoma fuscipes</u>	18	18	14	9	3
<u>Glaucornys sabrinus</u>	13	18	29	16	24
<u>Arborimus longicaudus</u>	24	32	20	38	42
<u>Peromyscus maniculatus</u>	15	12	10	14	14
Other mammalian prey	4	3	7	7	2
Nonmammalian prey	26	17	20	16	15

<sup>1/</sup> Northern Coast Range A and B are located on the Northern California Coast Range Preserve, Mendocino County, CA.

<sup>2/</sup> Other mammalian prey include: Clethrionomys californicus, Microtus californicus, Scapanus latimanus, Neurotrichus gibbsi, Sorex trowbridgii, Lasiurus cinereus, Mustela erminea, Tamias sp., and Sylvilagus sp.

<sup>3/</sup> Nonmammalian prey include various species of arthropods and birds.

\* Indicates year of successful breeding.

fledged young; of those territories with confirmed pairs, 45 percent successfully fledged young (Gutiérrez and others 1984). Similar year to year fluctuations were noted by Forsman and others (1984).

The year to year variations in the diet of representative pairs of spotted owls are shown in table 1. An increase in the frequency of large prey in the diet during breeding years was characteristic for all of the pairs of owls included in the analysis. Overall mean prey weights for breeding spotted owls ( $\bar{x}$  = 115 g, S.D. = 31) are significantly greater (one-tailed t test,  $P < 0.01$ ) than for nonbreeding owls ( $\bar{x}$  = 79 g, S.D. = 25) for 16 spotted owl pairs I studied intensively. A comparison of the frequency of spotted owl prey species, grouped by size, taken in breeding and nonbreeding years is depicted in figure 1.

<sup>1/</sup> Personal communication, R. Gutiérrez, Humboldt State University, Arcata, CA 95521.

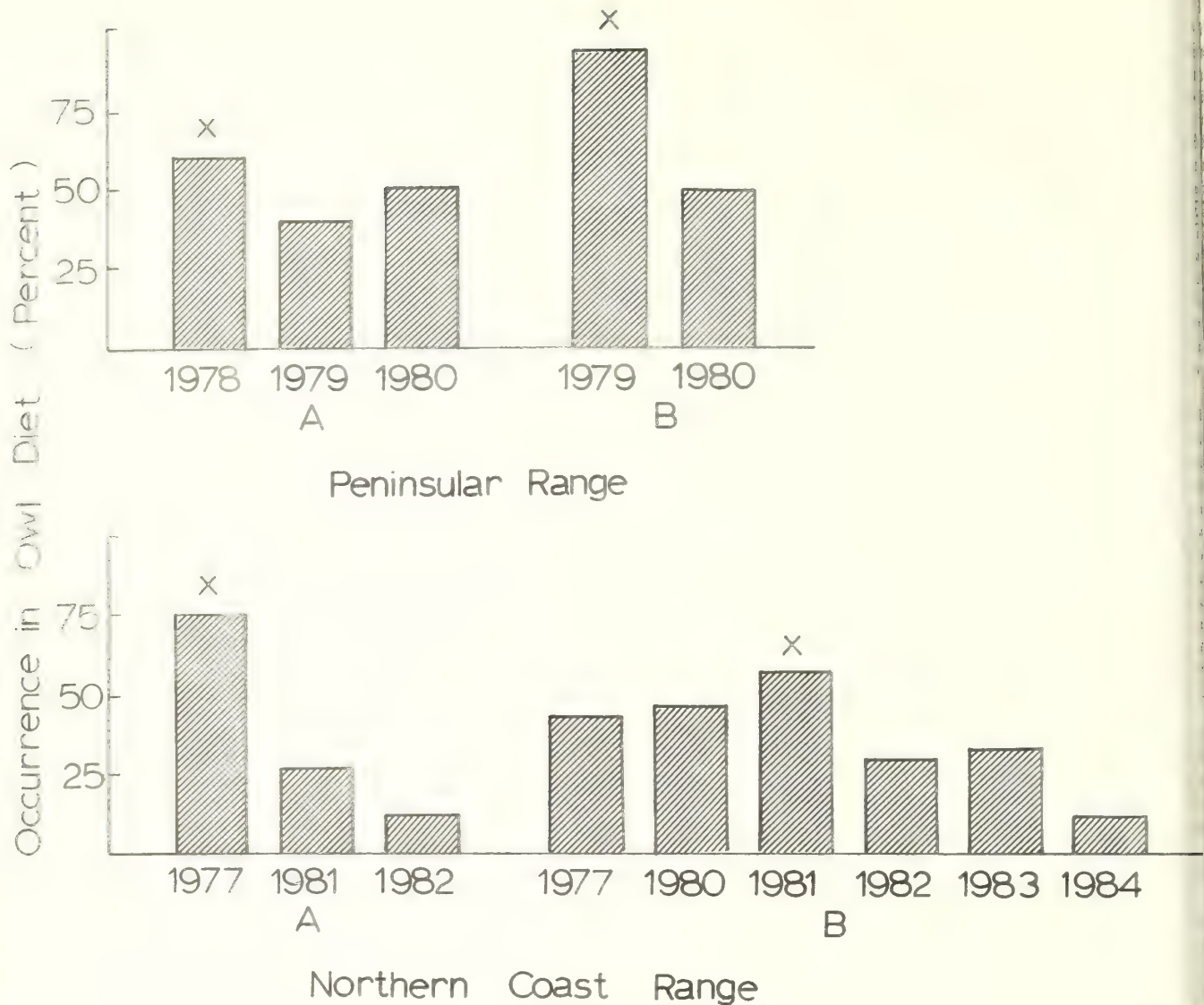


Figure 1. Prey frequencies in the diet of four representative pairs of breeding and nonbreeding spotted owls. Successful breeding years are denoted by an "X" above the histogram. Mammalian prey are grouped in two size classes; small prey -- less than 100 g; large prey -- 100 g or more. (Northern Coast Range pairs A and B are located on the Northern California Coast Range Preserve, Mendocino County, CA; Peninsular Range pairs A and B are located in Cuyamaca Mountains State Park, San Diego County, CA).

Differential breeding success rates in spotted owls may relate to basic habitat quality and varying habitat conditions. Habitat features, such as shrub cover, snag density, volume of dead and down wood, and canopy cover, are correlated with prey density and vulnerability (Maser and others 1979, Southern and Lowe 1968). These characteristics vary through the forest and so might account for some interterritorial differences in spotted owl breeding success. Fruit and mast production and weather-related

effects on prey vary among years and sites.

Food supply is most often cited as the ultimate cause in determining breeding success in raptors (Newton 1979). Other factors such as the individual owl's breeding experience certainly have some effect (for example, see Southern 1970); in at least one case, however, I found a second-year female spotted owl successfully breeding. Small mammal density estimates for northern California

1982 and 1983<sup>2/</sup> support a correlation between breeding success of spotted owls and fluctuations in rodent populations. This correlation must be viewed with skepticism as the primary prey species of spotted owls in northern California (Barrows 1980) are not sampled effectively by a single trapping method. Dusky-footed woodrats (*Neotoma fuscipes*), northern flying squirrels (*Glaucomys grinnellii*), red tree voles (*Arborimus longicaudus*), and deer mice (*Peromyscus maniculatus*) are important prey of spotted owls, but their dissimilar ecologies and behaviors require vastly different sampling methods for estimating their densities. Often densities can't be estimated and population indices are not comparable among species.

The energetic demand on a spotted owl pair feeding two to three owlets has not been measured but it must be considerably greater than that for nonbreeding pairs. The average weight of dusky-footed woodrats (269 g) or northern flying squirrels (115 g) (Forsman and others 1984) is four to twelve times that of deer mice (22 g) and red tree voles (27 g). The energetic benefits of taking larger prey, which require fewer trips to the nest, must be balanced against possible costs, such as greater difficulty of capture and a lower encounter rate, that result in longer search times for these larger animals.

For the spotted owl pairs I studied, the presence of large prey, such as dusky-footed woodrats and northern flying squirrels, is important to breeding success. The high frequency of large prey in the diet of breeding spotted owls could be a function of either the availability of the large prey or the owls' prey selection. Prey availability, however, partly determines prey selection. This distinction is important but is beyond the scope of the present paper. Understanding the ecology of the prey is fundamental to understanding the ecology of the predator. For the spotted owl, predator-prey relationships seem closely linked to reproductive success. Managing for spotted owls, therefore, should include consideration of those animals that serve as owl prey; ecological data on these prey species is required before we can understand the process behind the breeding pattern of spotted owls.

Current spotted owl management plans and habitat suitability models focus on habitat use by spotted owls, not on the owls' productivity. Habitat use alone is but one measure of habitat quality (Van Horn 1983). Breeding success is perhaps the best measure of habitat quality (Hilden 1965). Individual spotted owls and spotted owl pairs do occupy habitats that are apparently inadequate for consistent successful reproduction. Without immigration from areas that allow high

reproductive output, spotted owl populations in poor environments may not be able to persist.

Habitat suitability models for spotted owls need to be tested using the frequency of successful breeding. Such tests could be conducted by applying the models to the territories of pairs for which reproductive attainment has been measured. If the models cannot distinguish between the territories of reproducing and nonreproducing owls in terms of viability, then the models must be reexamined and refined. The models could also include terms reflecting the suitability of the territory for the owls' major prey species. The importance of regular breeding success in a population cannot be overstated. Factors that contribute to breeding success should be integral parts of habitat models. Such factors may vary temporally (for example, density) and long-term ecological studies may be necessary before good models can be developed.

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A REVIEW OF CURRENT NORTHERN SPOTTED OWL  
(Strix occidentalis caurina) RESEARCH  
IN WASHINGTON STATE

Harriet L. Allen and Larry W. Brewer

**ABSTRACT:** Two spotted owl research efforts are underway in Washington. One is a study of spotted owl population and ecology and is being conducted and funded by the Washington Department of Game. The other is a study to evaluate the effectiveness of the Spotted Owl Management Area (SOMA) concept and is funded jointly by the USDA Forest Service and the Washington Department of Game.

INTRODUCTION

The northern spotted owl was classified as "sensitive" by the state of Washington in 1982; this classification was changed to "threatened" in 1983. The Department of Game is currently conducting two research projects on the spotted owl.

The first project was initiated in 1982 and was funded by the Nongame Program of the Department of Game. It was established to provide facts about spotted owl ecology that either added to existing knowledge or clarified unique management questions in Washington. The objectives were to:

1. Determine the population distribution and status of spotted owls in Washington;
2. Monitor habitat use patterns of adult spotted owls;
3. Analyze habitats used by adults; and
4. Develop management recommendations for spotted owls in Washington.

A fifth objective, to monitor the dispersal of juvenile owls, was added during the second year of the study.

The second research project began in 1983 in cooperation with the USDA Forest Service to evaluate the effectiveness of the Spotted Owl Management Area (SOMA) concept. The cooperators are the USDA Forest Service Pacific Northwest Region, including the Mount Baker-Snoqualmie National Forest, the Gifford Pinchot National Forest, and the Olympic National Forest; the Pacific Northwest Forest and Range Experiment Station Old Growth Research and Development Project, Olympia, WA; and the Washington Department of Game. Objectives of the study were to:

1. Determine occupancy rates of SOMAs;
2. Determine how owls are using SOMAs; and
3. Determine how used areas differ from unused areas.

An overview of the methods and preliminary results of these two projects will be discussed individually.

SPOTTED OWL ECOLOGY STUDY

Population Levels and Status

We began our work on population evaluation by conducting a random survey throughout the potential range of the spotted owl in Washington. This included coniferous forests in both western Washington and on the eastern slopes of the Cascade Range. We divided the study area into

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20-km (12.5 mi) square cells and then randomly selected 53 cells in which to run surveys. The surveys were conducted along 32-km (20-mi) routes on roads or trails nearest the center of the cells. Routes were surveyed twice between May and September in both 1982 and 1983. Approximately 40 co-operators from State and Federal agencies and private organizations worked on the spotted owl survey each year.

Along the routes, cooperators stopped every 0.8-km (0.5 mi) and played a tape of a spotted owl call. The call was played at specified intervals over a 6-minute period at each listening station. All owl responses and the direction from which the responses were heard were recorded at each station.

Prior to the spotted owl surveys, each listening station was evaluated for habitat characteristics. Data were gathered for a 400-m-radius circle at each listening station and were recorded in a computer format. The data will be used to compare habitat among areas where spotted owls responded and areas where no owls responded.

In spring 1982 we called owls at 1,772 stations along 48 routes. During this effort we heard 44 spotted owls and 5 barred owls. In spring 1983 we surveyed 1,289 stations over 35 routes. We heard 33 spotted owls and 16 barred owls. We will attempt to estimate a minimum spotted owl population level from the census results. Data on barred owls will be used in a separate evaluation of barred owl distribution in Washington.

The sites where spotted owls were located during the surveys will be used as a random sample to help evaluate the classification status of the spotted owl in Washington. At each of these sites we will determine the habitat types, habitat fragmentation, land ownership, and future land use plans of an area 3.2 km (2 mi) square centered on the survey listening station.

The information from these analyses will be combined with other pertinent data to make a final determination of the status of the spotted owl in Washington. There are no plans to repeat the survey in future years.

#### Monitoring Habitat Use

The movement and habitat use patterns of 17 spotted owls have been monitored via radio telemetry for varying lengths of time within the 2-year study period. Seasonal and overall home ranges for adult male and female owls are being identified. Roosting and foraging concentration areas within the home ranges are being mapped.

To date, the home range size for the three most northerly pairs of owls have been evaluated. Two of these pairs were located near Mount Baker in the Mount Baker-Snoqualmie National Forest and one was in the Early Winters Creek drainage, Okanogan National Forest. The average home range for these pairs was 2499 ha (6,176 acres). The average home range for each individual owl was 1648 ha (4,071 acres).

These three preliminary home range estimates are conservative figures. The owls were monitored for periods of 120 to 300 days and may represent as little as 60 percent of the total home range (Forsman 1984). Preliminary evaluations suggest that home ranges are larger at the northern end of the species' range. We have made preliminary estimates of the total area of old growth with the home ranges of these three owl pairs using 1979 classified Landsat satellite imagery (Bremer and Eby 1983). The three home ranges evaluated contain an average of 749 ha (1,850 acres) of old growth per pair.

#### Analysis of Habitats Used by Adults

Habitat analyses of use areas will be compared to habitat analyses of randomly selected plots. We will also look for disparities in habitats selected by males vs. females. These habitat evaluations will be conducted in wet coniferous forest types in western Washington and in dry coniferous forest types on the eastern slopes of the Cascade Range. A major emphasis of this work will be to compare habitat needs of the northern spotted owl from the southern limits to the northern reaches of the species' range.

Throughout the project, spotted owl pellets have been collected at nesting and roosting sites and will be used to analyze food habits. Prey species will be identified and results compared with results from similar studies in California and Oregon.

#### Monitoring Juvenile Dispersal

Six juvenile spotted owls were trapped and equipped with radio transmitters in August 1983. These young birds dispersed from their nest areas in September and early October and were monitored throughout the following year by spot checks from aircraft. Dispersal routes of the juvenile birds were plotted; distance, direction, habitat selection, and mortality during dispersal are being evaluated.

The juveniles had a known mortality rate of 67 percent; as of June 1984, four of the six juveniles were dead. We were unable to locate two of the owls after extensive searches in May and suspect that the transmitters failed. Preliminary review of the data indicates that dispersal by juvenile spotted owls is random in both direction and habitat use. We tracked juvenile owls through a variety of habitats; only a few of them fit the current concept of adult spotted owl habitat. Dispersal distances exceeded 48 km (30 mi) in some cases. In those instances where two siblings were radio equipped, the birds dispersed from the nest area in generally opposite directions. The sample size in this study is small; however, the results should add to the understanding of juvenile dispersal when combined with the results of similar research conducted in Oregon and California.



The final objective of this research is to provide recommendations regarding the population status and management of the northern spotted owl in Washington. The target date for written completion of this research effort is July 1985.

#### EVALUATION OF THE SPOTTED OWL MANAGEMENT AREA (SOMA) CONCEPT

##### Occupancy Rates of SOMAs

A total of 46 SOMAs were randomly selected for the monitoring study: 19 in the Mount Baker-Snoqualmie National Forest; 17 in the Gifford Pinchot National Forest; and 10 in the Olympic National Forest. During the first field season (March - September 1984), we surveyed these 46 SOMAs to determine occupancy. Emphasis of surveying was to locate owls within the SOMAs during the day, rather than at night. SOMAs were surveyed at night when we were unable to elicit daytime responses. If after 7 surveys throughout the season we were unable to elicit a response, we considered the SOMA unoccupied.

We obtained at least one response from a spotted owl in 43 of the 46 SOMAs. We found no spotted owls in 3 of the 46 SOMAs. Of the 43 SOMAs with responses, we got daytime confirmations of a pair of owls in 12 SOMAs; and daytime confirmations of a single owl in 11 SOMAs. We got only night-time responses from owls in 20 SOMAs. Of these, seven were confirmed (according to Forest Service guidelines of three responses more than 72 hours apart) to contain at least one spotted owl. Thirteen SOMAs had at least one response, but were not verified to contain owls. We obtained barred owl responses in or near eight of the 46 SOMAs. We found no reproduction in any of the 46 SOMAs surveyed.

##### Use of SOMAs

We monitored five owls during the first field season. Preliminary results indicated an average summer range area of 968 ha (2,391 acres) (range: 17 ha (634 acres) to 1765 ha (4,362 acres)). From 0 to 85 percent ( $\bar{x}$  = 35.5 percent) of the locations were within the SOMAs; summer ranges overlapped the SOMAs by 0 to 44 percent ( $\bar{x}$  = 20.5 percent). Winter tracking is continuing on these SOMAs during 1984-85. We will monitor nine pairs of birds (three SOMAs on each forest) during 1985.

##### Comparison of Used vs. Unused Areas

Habitat analyses of used vs. unused areas will begin during the 1985 field season. Vegetation analysis that incorporates concentric circular plots (Spies 1983) randomly located in used and unused habitat, will be conducted in each of the home ranges of monitored owls. This effort will concentrate on those portions of home ranges that fall within the SOMAs.

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## OLD-GROWTH FOREST RETENTION FOR SPOTTED OWLS--HOW MUCH DO THEY NEED?

Eric D. Forsman and E. Charles Meslow

**ABSTRACT:** Pairs of adult owls in Oregon were studied by radiotelemetry to determine their home ranges and the acreages of old-growth forest in the home ranges. Six pairs were studied for 3 to 13 months. The pairs used 1,008-3,786 acres of old growth, averaging 2,264 acres per pair. The 1,008-acre figure provided the basis for management recommendations.

### INTRODUCTION

In 1980 the Oregon-Washington Interagency Wildlife Committee recommended that the amount of old-growth forest retained for individual pairs of spotted owls be increased from 300 to 1,000 acres (121-405 ha) (Oregon-Washington Interagency Wildlife Committee 1980). This recommendation was based on data gathered during radio-tracking studies of spotted owls in Oregon between 1975 and 1980 (Forsman 1980, 1981; Forsman and others 1984). During these studies, 14 adult spotted owls were fitted with radio transmitters and tracked for periods ranging from 3 to 13 months. In 6 cases, we were able to track both members of a resident pair of owls.

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At the end of the tracking period, the total home range of each pair of owls was determined, and the amount of old growth within each home range was determined from orthophotos. The minimum amount of old growth within the home ranges of the 6 pairs studied was 1,008 acres (405 ha) as reported by Forsman (1981) and Forsman and others (1984).

Subsequent to the 1980 revision of the spotted owl management plan, we received a number of requests to display all the data relating to the amount of old growth within the home ranges occupied by the pairs of owls that we studied (only the minimum acreage figure was cited in our initial reports). The purpose of this report, therefore, is to display the complete set of data concerning the amount of old growth within the home ranges of the 6 pairs of owls.

### OLD GROWTH PER PAIR

The area of old-growth forest in the home ranges of the radio-tagged pairs is shown in table 1. As described in Forsman (1980, 1981) and Forsman and others (1984), data from the 1A and 2C pairs

Table 1) should be viewed with caution because there was some question about the stability of those pairs. The other 4 pairs, however, appeared to be comprised of well-established individuals.

Table 1--Amount of old-growth forest within home range areas utilized by 6 pairs of radio-tagged spotted owls in northwestern Oregon

Pair no.	Home range size <sup>1/</sup>	Old-growth area
- - - - - Acres - - - - -		
1A	10,146	3,786
2A	3,945	2,092
5A	3,969	2,248
1C	10,440	2,262
2C	8,343	2,191
3C	2,840	1,008
Mean	6,614	2,264
Std. Dev.	3,419.5	886.5

<sup>1/</sup>Areas given indicate the total home range area used by each pair of owls. Home ranges utilized by individual owls were described in Forsman and others (1984).

The old-growth acreages used by the pairs of spotted owls in our studies do not appear unusual. Recent studies in California and Washington indicate that pairs of spotted owls use extensive areas of old-growth and mature forest in those areas as well (Sisco 1984; Solis 1983; Harriet Allen, pers. comm. 1984<sup>1/</sup>).

<sup>1/</sup>Washington State Game Department study in progress. Data on file with Harriet Allen, Washington State Game Department, Olympia, WA.

Because of economic concerns, the approach to spotted owl management in Oregon has been to manage for the minimum number of pairs necessary to sustain a genetically viable population and to provide each pair with a minimum amount of old-growth habitat. This approach involves a high degree of risk because it is unlikely that any species will prosper if it is reduced to minimum numbers and, at the same time, provided with a minimum amount of suitable habitat. To mitigate the effects of minimal numbers and minimal areas of habitat, managers should attempt to ensure that old-growth habitat that is retained for spotted owls is of the highest quality available.

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## JUVENILE SPOTTED OWL DISPERSAL IN NORTHWESTERN CALIFORNIA: PRELIMINARY RESULTS

R. J. Gutiérrez, Alan B. Franklin, William Lahaye,  
Vicky J. Meretsky, and J. Patrick Ward

**ABSTRACT:** Dispersal ecology of juvenile spotted owls was studied in northwestern California during 1982 and 1983. Breeding spotted owls were not found in northwestern California in 1982. In 1983, we radio-marked 13 juvenile owls. Eleven owlets survived to disperse between 2 September and 23 October 1983. The total dispersal distances for these owlets ranged from 30 km to 156 km ( $x = 78$  km). The final dispersal distance measured as a straight line from the nest to the location of juvenile mortality or transmitter failure ranged from 20 km to 98 km ( $x = 45$  km). An analysis of dispersal directions using circular statistics showed that, as a group, juveniles dispersed in a southerly direction ( $154^\circ$ ). We lost radio contact with four of the owls, while the remaining seven died. Causes of mortality included a presumed accident (1), animal predation (1), starvation (3), undetermined (4). The management implications for these preliminary results are discussed.

### INTRODUCTION

The northern spotted owl (*Strix occidentalis caurina*) is closely associated with old-growth Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) forests from southwestern British Columbia through northwestern California

(Forsman 1980, Solis 1983). The rapid harvest of these forests in the Pacific Northwest has led to a population decline of the northern spotted owl (Forsman and others 1984, U. S. Fish and Wildlife Service 1982). In response to this decline, the USDA Forest Service established Spotted Owl Territories (SOTs) that are developed from habitat and home range studies conducted by Forsman (198 and Solis (1983). Although data exist for establishing guidelines for SOT habitat quality and quantity, no data exist for determining an appropriate distribution of SOTs.

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The maintenance of effective population size (Barrowclough and Coats 1985) and the correct spatial organization of SOTs cannot be adequately predicted without an understanding of dispersal. The importance of animal dispersal to demography, genetics, and social behavior has

been documented for a wide variety of taxa (Greenwood 1980, Lidicker 1962, Lidicker and Aldwell 1982, Southwood 1962). For this paper, dispersal is defined as nonmigratory movement by an individual beginning with its departure from the natal area and ending with the establishment of a breeding territory. In this paper, we present some initial observations on the dispersal of juvenile spotted owls in northern California and discuss the implications for the management of this species.

#### MATERIALS AND METHODS

The dispersal ecology of northern spotted owls was studied in northwestern California from 1982 to 1983. Because of a region-wide breeding failure of spotted owls in 1982, data on dispersing juveniles were not collected until 1983.

Our study area encompasses portions of the Six Rivers, Klamath, and Shasta-Trinity National Forests in northwestern California. The area is dominated by rugged topography and numerous river and stream systems. Elevations of the study area range from 300 m to 1500 m. The climate is typically wet and cool in winter, with snow at higher elevations; summers are hot and dry. Average yearly precipitation for the study area is approximately 142 cm.

The study is limited to Douglas-fir forests because spotted owls appear to be more abundant in this habitat (Forsman and others 1984); this vegetation type is also the most extensive and

valuable of the old-growth forests in northwestern California. The vegetation series are more completely described by Sawyer and others (1977) and Solis (1983).

Nests and juveniles were located in the manner described by Forsman (1984). Juveniles were captured using a dip net constructed of mist netting. Each captured juvenile was banded with a U. S. Fish and Wildlife Service aluminum leg band and outfitted with a radio transmitter attached to a backpack of 5-mm teflon ribbon (Solis 1983). The birds were released within 18 min and observed to determine behavioral reactions.

Radio-marked owls were monitored using the methods outlined by Solis (1983). Owl locations were plotted on U. S. Geological Survey topographic maps (1:24000) using a minimum of three compass bearings from monitoring points with the bearing describing the peak radio signal (Springer 1979).

Juvenile owls were initially monitored at least once a week to determine location or mortality prior to dispersal. We tracked dispersing juveniles from the ground as closely as terrain and weather conditions permitted. Telemetry-equipped aircraft were used to relocate owlets lost during ground tracking and for monitoring owlets in inaccessible areas.

Dispersal directions and direction-distance vectors were analyzed using circular statistics (Batschelet 1981).

Table 1--Summary of dispersal distances and fates of 13 juvenile spotted owls, *Strix occidentalis aurina*, from northwestern California, 1983

Owl	Sex <sup>1/</sup>	Date Sighted	Date Banded	Date Died	Total Distance km (mi)	Final Distance km (mi)	Fate
Onto	M	30 Jun	26 Jul	22 Sep	0 (0)	0 (0)	Dead
Ang	U	1 Jul	7 Jul	9 Oct	32 (19)	26 (16)	Dead
Itus	U	30 Jun	6 Jul	25 Nov	128 (77)	99 (62)	Dead
Ertha	U	18 Aug	23 Aug	2 Feb	45 (27)	22 (13)	Unstable <sup>2/</sup>
Erlyn	U	11 Aug	19 Aug	20 Mar	163 (98)	67 (41)	Dead
Anger	M	22 Jun	6 Jul	29 Mar	63 (38)	44 (27)	Dead
Heech	U	23 Jun	11 Jul	17 Jan	77 (46)	42 (26)	Stable <sup>3/</sup>
Hong	U	23 Jun	13 Jul	21 Nov	73 (44)	56 (35)	Dead
Ake	U	24 Jun	20 Jul	20 Dec	138 (86)	42 (26)	Dead
Imo	U	24 Jun	14 Jul	25 Nov	60 (36)	53 (32)	Dead
Ugarbaby	U	17 Jun	12 Jul	2 Sep	0 (0)	0 (0)	Dead
Arpy	U	17 Jun	8 Jul	3 Jan	45 (27)	23 (14)	Unstable
Hrew	U	6 Jul	21 Jul	17 Jan	70 (42)	35 (22)	Unstable

<sup>1/</sup>Sex M = male; U = unknown.

<sup>2/</sup>Unstable = dispersal in progress when transmitter failed.

<sup>3/</sup>Stable = settled in a restricted area before transmitter failed.

## RESULTS AND DISCUSSION

### Dispersal Patterns

All marked, surviving juveniles dispersed between 2 September and 23 October 1983 (table 1). Sixty-four percent (7 juveniles) dispersed within a 9-day period from 19 September to 27 September. The degree of parental care at the time of dispersal was not known, but after a bird left its natal area, it did not return.

Dispersal distance and direction.--The total dispersal distance, which is the sum of dispersal movements for an individual owl, ranged from 30 km to 156 km (19 mi to 97.6 mi) with a mean of 78 km (48.4 mi) (table 1). The final distance measured as a straight line from the nest to the location of the juvenile mortality or transmitter failure ranged from 20 km to 98 km (12 mi to 61.5 mi) with a mean of 45 km (28.3 mi).

The directions in which dispersing owlets traveled were averaged and represented as vectors of dispersal (fig. 1). The  $r$  values associated with each vector represent the measure of concentration of the individual directions taken by each bird. The higher the  $r$  value, the more

consistently the juvenile moved in a single direction. Observations from all of the birds were combined to calculate a group direction or vector ( $\emptyset$ ). The group direction for all juveniles was  $\emptyset = 154^\circ$  with  $r = 0.35$ . The low  $r$  value indicated that directions taken between dispersal movements were variable. Rayleigh and Rao's spacing tests (Batschelet 1981) showed the five birds were heading in a particular compass direction. The remaining birds' movements were not shown to be significantly different from a random distribution. The group direction ( $\emptyset$ ), however, was significantly different from a random distribution according to both the Rayleigh and Rao's spacing tests. As a group, the juveniles therefore appeared to be moving in a southerly direction ( $\emptyset = 154^\circ$ ; fig. 1).

For each owl, a bivariate vector was plotted using distance and direction from the nest to the owl's final known location (fig. 2). A mean vector ( $M$ ) of  $188^\circ$  and 34 km (21.1 mi) was calculated for the sample of vectors. Again, as a group, the juveniles appeared to be moving in a southerly direction.

Hotelling's confidence ellipse (Batschelet 1981) was calculated to determine the area covering

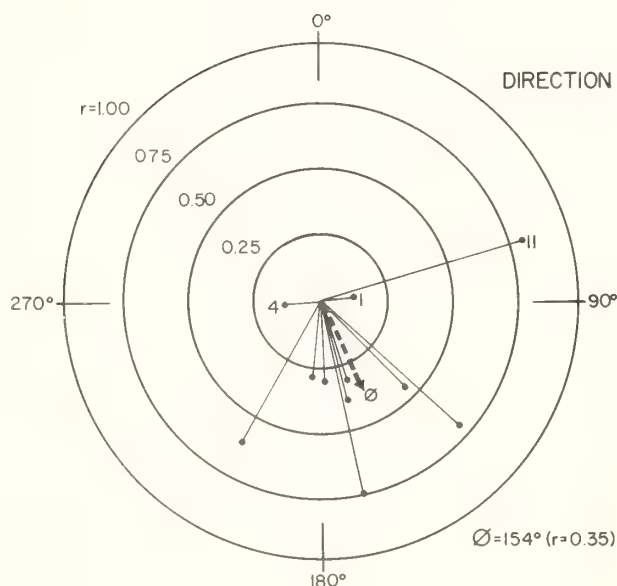


Figure 1.--Direction vectors for 11 dispersing juvenile spotted owls, *Strix occidentalis caurina*, from northwestern California, 1983.  $\emptyset$  = an overall group direction;  $r$  = the measure of concentration of  $\emptyset$  (Batschelet 1981).

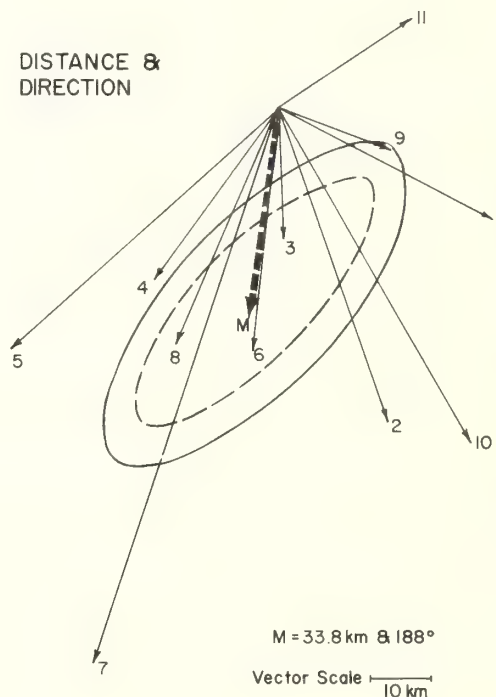


Figure 2.--Bivariate vectors using distance and direction from nest to final location for 11 dispersing juvenile spotted owls, *Strix occidentalis caurina*, from northwestern California, 1983.  $M$  = the sample mean; the outer ellipse is one standard deviation around the mean; the inner, a 95% Hotelling's confidence ellipse (Batschelet 1981).



the true population center of dispersing juvenile owls with 90 percent probability. In other words, with the starting point at the nest origin there is a 90 percent probability that the population mean of final dispersal locations of juvenile spotted owls would be included within this ellipse.

In the circumstances allowed us to closely follow individuals that were dispersing, we found that these birds typically moved rapidly and directionally. The average rate of movement of all birds was 8 km/day (5.03 mi/day), with a range of 1.6-17 km/day (1-10.9 mi/day).

After an initial rapid movement from the natal area, most ( $n = 8$ ) of the owlets attempted to disperse. Three of these owlets, which were monitored closely, had home ranges of 362 to 461 (882 to 1125 acres). After settling, six of the owlets died or their transmitters failed. The three that survived continued to disperse after remaining four to ten weeks in their respective areas. One owl was monitored and foraged for several days in the same area on three separate occasions and made two round trips of 6 and 50 km (4 and 31 mi). The other owl died 19 km (12 mi) from the area during its final departure.

Effect of barriers and habitat on dispersal.---  
Topographic and topographic barriers did not noticeably affect direction of dispersal. Owlets frequently crossed major ridges and rivers during dispersal; for example, one bird crossed three large rivers (75-100 m width) and two major ridges (1200-1500 m elevation) during its dispersal.

Juvenile owls readily crossed habitats in northwestern California that would be classified as unsuitable for spotted owls (Gutiérrez and others 1984, Solis 1983). Although owlets frequently entered these areas, they often died there as well. Unsuitable habitats (for example, clear-cuts and oak woodlands) may be effective barriers to dispersal, but this does not seem to deter the owlets from entering them.

#### Juvenile Mortality

All of our marked juveniles ( $n = 7$ ) that survived to disperse, and whose transmitter batteries did not fail, died during dispersal. Causes of mortality included predation (1), starvation (3), and undetermined (3). Four transmitter batteries failed before they could be replaced. Two juveniles died before dispersing, one from an apparent accident (punctured eye) and the other from unknown causes. Because none of the juveniles survived to established breeding territories, the distances recorded in our study cannot be considered net effective dispersal distances.

It has long been known that dispersing animals incur high mortality rates (Howard 1960, Lidicker and Caldwell 1982). Juvenile tawny owls (*Strix* *macroura*) exhibited average first-year mortality rates between 47 and 66 percent under normal

conditions (that is, without decreasing habitat limitations) (Southern 1970), Barrowclough and Coats (1985) calculated an expected first-year survivorship for spotted owls to be 19 percent.

A population of owls could, clearly, not maintain itself with a mortality of 100 percent such as we observed. Our sample size is small enough that one might expect the entire group to die by chance alone (Barrowclough and Coats 1985). A larger sample size may be needed to detect the 19 percent survivorship. Despite such a high first-year mortality rate, spotted owls may be sufficiently long-lived that they could replace themselves within their reproductive lives.

#### MANAGEMENT IMPLICATIONS

There are three important implications of our preliminary findings. First, our study demonstrates that juvenile spotted owls move considerably farther than previously observed (Forsman and others 1984). Yet, our data are consistent with those reported in this symposium by Miller and Meslow (1985). Owlets are aggressive dispersers and travel rapidly over topographic barriers and into or through unsuitable habitat. Inter-SOT distances should not, however, be increased to reflect these long dispersal distances. Because owlets move directionally, the probability of a juvenile owl encountering a SOT would decrease as the inter-SOT distance increases.

Second, we do not know how long-term population viability will be affected if adequate dispersal sinks (as defined by Lidicker 1962, habitats where nonbreeding owls can persist until breeding habitat becomes available) are not available for juvenile owls. Because spotted owls are probably long-lived, SOTs may be occupied for a long time. A SOT management scheme without consideration for dispersal sinks must depend almost entirely on the current year's productivity to fill available SOTs. Thus, the most productive habitat or pairs of owls should be maintained to ensure adequate productivity. We believe that establishing SOTs with pairs of owls that show sporadic or no productivity are inadequate for maintaining a viable population. The reasons for this are: (1) adults have a variable reproductive pattern (Gutiérrez 1985, Gutiérrez and others 1984); (2) juveniles have a low survivorship (Barrowclough and Coats 1985, Forsman and others 1984, Miller and Meslow 1985); and (3) there is continuing habitat deterioration.

Third, the influence of dispersal on the survivorship of juvenile spotted owls and effective population size is presented by Barrowclough and Coats (1985). If the high juvenile mortality we observed is, in part, due to deteriorating habitat (that is, increased patchiness and loss of old growth), then we might predict (1) lower survivorship of juveniles as this deterioration continues and (2) an increase in dispersal distance required to reach suitable habitat. In turn, effective population size is strongly influenced by these dispersal

distances (Barrowclough and Coats 1985). Ultimately, the long-term viability of spotted owls in the Pacific Northwest will be a function of effective population size and colonization of habitat patches that are partially dependent on dispersal ecology (Barrowclough and Coats 1985, Frankel and Soulé 1981, Gutiérrez and others 1984, Schaffer 1985). SOTs should be established with appropriate habitat characteristics, as described by Forsman and others (1984) for mesic Oregon, by Solis (1983) and Gutiérrez and others (1984) in northwestern California, and by Layman (1985) in the Sierra Nevada. SOTs should not be designated solely on their value (or lack thereof) as a timber resource. Many of the most productive habitats appear to be in valuable timber stands. If adequate protection is to be provided for spotted owls, SOTs must be placed in these stands, commercial values notwithstanding. Above all, spotted owl management plans must be allowed some flexibility (Gutiérrez and others 1984) to accommodate new and relevant findings on spotted owl dispersal.

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## GENERAL HABITATS AND MOVEMENTS OF SPOTTED OWLS IN THE SIERRA NEVADA

Stephen A. Laymon

**ABSTRACT:** This paper reports a summary of a 3-year research project on the California spotted owl in the central Sierra Nevada of California. Owls with radio transmitters were tracked and vegetation parameters were measured on summer, autumn, and winter roosting plots and on randomly located plots within the owl's home range. The discovery of downslope migrational movements and establishment of winter home ranges in the foothill woodland was a significant finding which may indicate a subspecies difference and which raises previously unthought of management problems. The ramifications of these new management issues are discussed.

### INTRODUCTION

A great deal of research has been undertaken on the northern spotted owl (Strix occidentalis caurina). Forsman and others (1984) completed eight seasons of field work in west-central Oregon, including two years of radio telemetry on two study sites. Gutiérrez and associates at Humboldt State University, Arcata, California, have conducted a 5-year research effort to examine winter and summer habitat use and juvenile dispersal of spotted owls in northwestern California. The California subspecies, Strix occidentalis occidentalis, which ranges from northeastern Tehama County south through the Sierra Nevada and the high mountain ranges of southern California, and in the Coast Range from southern California north to Monterey County, has received little attention from researchers. The only published information consists of work on thermoregulation (Barrows 1981) and on food habits (Barrows 1980, Marshall 1942).

The current study, from 1982 to 1984, was designed to fill in gaps in the knowledge of the natural history, life history, habitat selection, and juvenile dispersal in the Sierra Nevada population of the California spotted owl, and to determine if there were differences between the northern and California subspecies. Presented here is an outline of the general accomplishments and progress of the study.

### STUDY AREA

The study was conducted primarily between the middle and south forks of the American River in **El Dorado and Placer Counties, California**. Elevation was 300-2000 m and the study area encompassed 500 km<sup>2</sup>. University of California at Berkeley Blodgett Forest Research Station, near Georgetown, California, was the base of operations for the study. Habitat types in the study area included mixed conifer forest, red fir forest, yellow pine forest, pine-oak woodland, and oak savannah.

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## METHODS

### Radio Telemetry

A total of 13 adults and 12 juveniles were equipped with radio transmitters during the 3-year study. Adult foraging sites and winter roosting sites were located using triangulation methods from known locations. Summer and autumn roosting sites for both adults and juveniles were located visually with the aid of radio telemetry.

### Vegetation Sampling

Vegetation was sampled on 15-m-radius plots entered on roosting, foraging, and random trees. All trees greater than 10 cm diameter at breast height (d.b.h.), total height, height of first foliage, and average radius of foliage. Additionally, tree species, shape, and condition were recorded. Canopy closure was estimated using an inverted monocular with plastic tannin grid. Shrubs and trees smaller than 10 cm d.b.h. were sampled with a 0.5-m-wide belt transect. Dead and down material was sampled with line intercept methods (Brown 1974). Slope and aspect were also measured. Sampling was done at randomly selected roost and foraging sites and at sites determined by coordinates randomly selected from a grid placed over a map of each pair's home range.

## RESULTS

### Vegetation Sampling

Vegetation was measured at 10 summer (June–August) roosting sites and 10 summer foraging sites for each of 12 paired adults. Roosting sites and foraging sites were characterized for nine adults during the autumn (September–October). Twenty random points were surveyed within the home range of each pair. Vegetation was also sampled at 5 roosting sites and at 15 random points in inter-use areas of four birds. Sampling on a total of 50 vegetation plots was also completed at juvenile roosting sites. Analysis of vegetation data is not yet complete. A cursory look at the data shows little similarity along summer roosting sites, foraging sites, and randomly selected sites, and between winter roosting and winter randomly selected sites. Great similarity is found between autumn roosting and autumn foraging sites.

### Food Habits

Approximately 800 pellets of regurgitated, undigested portions of prey items have been collected and analyzed. A much higher diversity of prey items by species has been found in this study than in others. The 1982 data, based on eight pairs of owls and 522 food items, show an almost equal division of biomass eaten: northern flying squirrels (*Glaucomys sabrinus*), 40 percent; dusky-footed woodrats (*Neotoma f. umipes*), 22 percent; western gray squirrels (*Sciurus griseus*), 22 percent; and birds, 16 percent. The 1983 data show a similar pattern.

## Reproductive Success

Reproductive success has been quite low for the three years of the study. During 1982 and 1983 only 1 of 14 pairs produced young (7 percent). In 1984, 3 of 12 pairs produced young in the Eldorado National Forest study site and 3 of 10 pairs produced young in the Stanislaus National Forest -- a success rate of 27 percent.

### Juvenile Mortality

I observed 11 juveniles during the post fledging–predispersal period. Seven of the juveniles died; three dispersed. I am currently monitoring one juvenile that has not yet dispersed. Of the seven deaths, four were attributed to predation and three to starvation.

### Migratory Movements

I monitored four adult owls by radio telemetry during autumn 1983. In late October the four owls began moving downslope to the southwest. One bird was tracked daily during this time. It moved 3–6 km each night, traversing the 29 km between breeding and wintering sites in seven nights. This bird dropped in elevation from 1600 to 930 m. The other three owls moved from 19 to 32 km and dropped in elevation an average of 700 m. All four owls circulated through areas of 300–2000 ha, which appeared to be a winter home range. The birds remained in the wintering areas until at least late February. All four birds returned by mid-April to their nest sites used the previous year.

The areas occupied during the winter were pine-oak woodlands in contrast to the mixed conifer forest used during the summer. All wintering areas were below the level of persistent winter snow, which is approximately 1300 m in this part of the Sierra Nevada.

## DISCUSSION

All findings from the study indicate that natural history patterns of the California spotted owl in the central Sierra Nevada differ significantly from those of the northern spotted owl in northwestern California and Oregon. The migratory movement is of special interest. It indicates a significant behavioral difference that may be linked to subspeciation.

Migration also creates significant management complications because it takes owls from summer home ranges primarily in USDA Forest Service jurisdiction to winter home ranges which are primarily in areas that are privately owned. In addition, the winter home ranges are in the elevational and geographical area that is growing faster in human population than any other area in California.

The migratory movement underscores the importance of multiple studies on a species in different geographical areas to determine the range of a

species' behavior. It also points out the dangers of imposing a management plan for a species in a geographical region other than the one where the ecological data, on which the plan was based, was gathered. On the west slope of the Sierra Nevada, USDA Forest Service management plans designed to maintain breeding populations of spotted owls may not be adequate if the majority of the owls are dependent on winter habitats in the foothill zone, which is growing fast in human population. A much more complicated management effort involving USDA Forest Service, United States Department of the Interior Bureau of Land Management, California Department of Fish and Game, California Department of Forestry, county Boards of Supervisors, and the California State Legislature may be necessary to provide year-round habitat for the spotted owls. Factors such as fuelwood harvest, clearing woodland areas for cattle grazing, and subdivision of land for housing are all impacts on the foothill zone; these impacts will certainly become more serious in the future. This study has pointed out a previously unknown problem that makes the management of spotted owls in the Sierra Nevada a much more difficult task than previously thought. Whether management agencies can meet this challenge will be seen in the years ahead.

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## DISPERSAL DATA FOR JUVENILE SPOTTED OWLS: THE PROBLEM OF SMALL SAMPLE SIZE

Gary S. Miller and E. Charles Meslow

**ABSTRACT:** Collection and interpretation of dispersal data for juvenile northern spotted owls (*Strix occidentalis caurina*), based on preliminary information from Oregon, are discussed. Criteria for determining when dispersal ends and methods of measuring dispersal distances are examined. Small sample sizes, caused by unpredictable reproduction and high juvenile mortality, account for much of the problem in studying juvenile dispersal.

### INTRODUCTION

Dispersal, on some scale, is an attribute of most animals. Dispersal and its patterns are basic to a species' life history strategy and affect nearly all aspects of a species' ecology and behavior (Horn 1983). Dispersal is the mechanism that brings about colonization of unoccupied areas and gene flow between populations. Dispersal has also been proposed as an important factor in population regulation (Lidicker 1962). While the importance of dispersal has been recognized for some time, the ability to obtain detailed dispersal information has been limited for most species.

Dispersal has been defined differently by various investigators. Howard (1960) defines it as "the movement the animal makes from its point of origin to the place where it reproduces or would have reproduced if it had survived and found a mate." Others simply define dispersal as the movement of an individual from its natal area to a new area or succession of areas (Greenwood 1980, Shields 1982). These later authors add, however, that successful dispersal requires the individual to reproduce following dispersal movements. We will distinguish between dispersal and successful dispersal.

Information on avian dispersal has historically come from band returns or sightings of marked individuals (Erickson 1938, Gibb 1954, Johnston 1956, Kluijver 1951). Dispersal information, for owls in particular, has been gained from various banding studies (Houston 1978, Stuart 1952, Van Camp and Henny 1975), and although helpful in determining some aspects of dispersal, the information relies on band returns from the public and is therefore somewhat biased. Information on an individual's movements is not available, and locations where bands are recovered probably do not accurately portray the individual's total movements. Biases occur with the area the dispersing birds move through. In more populated areas, the chances are higher that a bird will be recovered or sighted. Bands as identification marks have also been used in retrapping efforts on specified study areas to determine dispersal between birth-place and breeding place (Newton and Marquiss 1983). Such studies use data both from band returns from the general public and from birds retrapped on the study areas. Studies with confined sampling areas provide an appraisal of juvenile dispersal that is biased toward short-distance dispersers.

A distinct improvement is provided by radio telemetry, which reduces much of the bias of band return studies by eliminating the reliance on a confined study area and band returns from the public. Radio telemetry has been used successfully for a number of years to study dispersal of mammals (Phillips et al. 1972, Shirer 1968; Storm and others 1976). Only recently has telemetry been employed to gather detailed dispersal information on birds.

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We discuss some of the problems encountered when attempting to collect and interpret dispersal data gathered in Oregon from juvenile northern spotted owls (*Strix occidentalis caurina*). Actual data used are preliminary and represent primarily a single year's effort.

#### SPOTTED OWL DISPERSAL STUDY

Results from recent studies have shown that northern spotted owls depend on old-growth forests and are declining in numbers as these forests are harvested (Forsman and others 1984, Solis 1983). As the number of spotted owl pairs decreases and the habitat becomes more sparse, the chances increase for pairs or groups of pairs to become reproductively isolated. Isolated owls do not contribute to the maintenance of a diverse gene pool. The distance between adjacent pairs or groups of breeding owls must be such that dispersal and recruitment can replace losses (deaths or emigrations) among existing pairs and provide for colonization of suitable unoccupied habitats. A study of dispersal should help formulate better criteria for minimal spacing between pairs. Some limited work on juvenile dispersal of spotted owls has been reported from both Oregon and California (Forsman and others 1984, Solis 1983). There are studies currently underway in both California and Washington (see respectively, Gutiérrez and others 1985 and Allen and Brewer 1985), as well as our study in Oregon, to examine dispersal of juvenile spotted owls in more detail.

In spring 1982, a radio-telemetry study was initiated in Oregon to obtain dispersal information about the northern spotted owl. Study areas (fig. 1) were in the western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) zone of western Oregon, an area dominated by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and western hemlock (Franklin and Dyrness 1973). Specific study sites within the western hemlock zone were necessarily determined by locations of nesting owls. Two broad regions were chosen (the Cascade and Coast Ranges), but specific study locations within these regions necessarily changed from year to year. Forests in the Cascades were less fragmented than were those in the Coast Ranges.

In addition to addressing appropriate interpair spacing, this dispersal study provided an opportunity to document other components of the species' life history, such as breeding frequency, nesting success, juvenile survivorship, and recruitment. Mortality of juvenile spotted owls has been examined only briefly (Forsman and others 1984). Age at first breeding and rates of recruitment to the breeding population are unknown.

#### Collection of Dispersal Data

Life history characteristics of the spotted owl create many of the limits to the study of dispersal. For example, spotted owls lay relatively small clutches (1-3) and do not breed every year (Forsman and others 1984). As a result, researchers must work with small sample sizes of

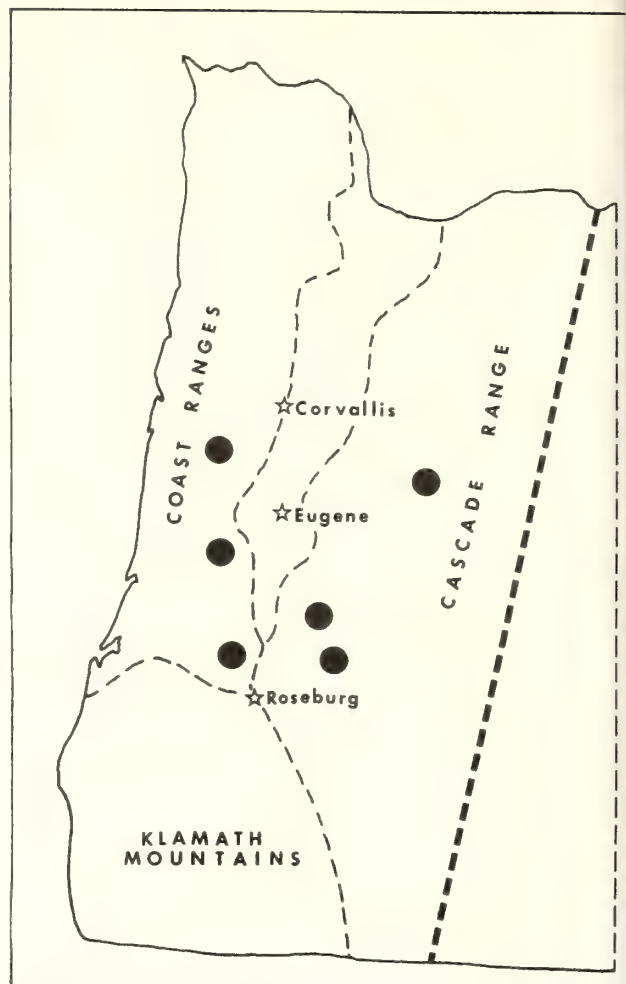


Figure 1--Northern spotted owl study areas in western Oregon.

dispersers. In addition, substantial mortality occurs prior to dispersal (Forsman and others 1984), making it very difficult to follow significant numbers of dispersing juveniles. Forsman and others (1984) document the fate of 29 young between the time of fledging and the end of August; 19 survived the interval, yielding a mortality rate of 35 percent. We found mortality rates to be the same with a similar sample size for an equivalent time period. Use of radio transmitters also allowed documentation of mortality for almost an additional month up to the time of dispersal (young owls began dispersal between 7 September and 4 November). Mortality following fledging rose to about 45 percent for this total predispersal period.

Thus, with a mean of two young fledged per successful nest (Forsman and others 1984), coupled with the high predispersal mortality rate, an average of one successful nest per "useful" dispersing juvenile must be located. This is a formidable task, especially if study design dictates partitioning of the sample into various categories (for example, habitat fragmentation and stand ages). In 1983 we located 33 young that fledged from 19 successful nests. We relocated these young at least weekly until young were large enough to carry the transmitters. Twenty-five



young were still alive at the time transmitters were put on (July-August) and 18 survived to disperse.

Mortality seems to continue at a relatively high rate during dispersal. Of the 18 juveniles that survived to disperse, only 3 were still alive the following May. Three other dispersers could not be located, status undetermined.

When radio signals for dispersing juvenile owls were lost, extensive aerial searches were initiated to relocate them. If relocation was unsuccessful, we could not establish with certainty whether the owls dispersed beyond the range of the aerial searches (unlikely) or if their transmitters failed. Radio failure, although uncommon, does occur. When a radio-marked disperser disappeared, for whatever reason, we faced a dilemma: how to employ dispersal data for such individuals up to the time of disappearance. The conservative approach was to eliminate from the sample of dispersers any owls that could not be accounted for (disappear). Data gathered from such individuals could be incorporated into any summary of dispersal so long as the bird was located throughout the period examined. Also, because such owls were not necessarily dead, they could not be incorporated into most mortality calculations except under similar time constraints. The value of all data acquired on any individual that eventually "disappeared" was greatly diminished because there was no documented end point--successful dispersal or death.

Short-term studies amplify the impact of the above life history attributes. When trying to examine dispersal in a quantitative rather than qualitative way, the small sample size limits the significance of any statistical differences.

## MEASURING DISPERSAL

### End of Dispersal

Because of biological, logistic, and budgetary limitations, projected sample sizes for a study of owls will be small: An annual goal, for a 3-person field team, of 20-25 dispersing juveniles is realistic. If the level of mortality we observed is typical, few successful dispersers will be documented. If an adequate number of successful dispersers is not available, then criteria must be set to evaluate the level of resolution of dispersal at hand. Various levels of defining when dispersal ends can be adopted. Of these, the most restrictive definition that the data will permit should be selected. The following are examples in decreasing order of resolution: (1) owl is paired, breeds, and fledges one or more young; (2) owl is paired during the breeding season; (3) owl is settled in a definable area (3 months or longer) during the breeding season; (4) owl is settled in a definable area (3 months or longer) during the nonbreeding season; and (5) owl disperses but dies before it has settled for 3 months.

In our study there are no juveniles in the first two categories. Three juveniles fall into category 3, two into category 4, and eleven into category 5. As is evident from the data, it will take several years of field study to obtain any sort of sample size in the first two categories. Thus, it may be necessary to adopt a less restrictive definition of dispersal in order to have a reasonable sample to work with and to base management recommendations on. Both researchers and forest managers need to recognize these limitations and jointly participate in deciding the level of resolution acceptable for management decisions.

### Measuring Dispersal Distances

How to effectively measure dispersal distances or to express dispersal depends on which role of dispersal is examined. One role of dispersal is as the mechanism that brings about gene flow. Although all movements between birth site and breeding site are important, as they contribute to survival or lack thereof, only straight-line distances between these sites measure dispersal as it contributes to gene flow. In our study, juveniles have moved up to 76.8 km (straight-line distance) from their birth site. But survival of such long-distance dispersers has been low. Dispersal, as it relates to gene flow, is functional only if the owl survives to breed. The appropriate measure is the straight-line distance between birth site and breeding site.

The other role of dispersal is the colonization of vacant habitats. To determine encounter rates of potentially vacant habitats by dispersing juveniles, total distance moved between birth site and breeding site (summation of day-to-day movements) are more appropriate than the straight-line distance. If daily movements are determined, these could be related to the type of habitats encountered. Consideration of daily movements allows other important characteristics of dispersal to be documented as well. Patterns of dispersal, such as the use or nonuse of major drainage systems, can only be plotted through the total movements of the juvenile.

Effective dispersal distance--Other researchers have expressed dispersal distances in terms of the number of home ranges moved across (Greenwood and others 1979; Shields 1982). Shields (1982) states that "dispersal distances are normally reported as population averages of the absolute distances individual propagules move. This erroneously implies that dispersal is a continuous phenomenon, ignoring the contributions of normal individual spacing to dispersal." The individual spacing that effects dispersal can be estimated from the size of the home range. Effective dispersal distance is the median dispersal distance divided by the average diameter of the area occupied exclusively by sedentary individuals (that is, home range diameters). It is a term describing dispersal in relation to home range size (Greenwood 1980, Shields 1982). Effective dispersal distance thus does not provide a measurement of distance but rather provides an index of population with respect to other populations or



Table 1--Median and mean straight-line distances moved by spotted owls in west central Oregon (from natal area to death or settling)

Categories	Sample Size	Dispersal Distances		
		Median	Mean	Minimum-maximum
-----Kilometers-----				
Successful dispersers (fledged 1 or more young)	0	--	--	
Owl is paired (breeding season)	0	--	--	
Owl is settled (breeding season)	3	10.8	26.3	(4.8-57.9)
Owl is settled (nonbreeding season)	2	--	17.8	(14.8-20.8)
Owl disperses but dies before settling	11	24.0	33.4	(4.8-76.8)

species. Studies employing effective dispersal distances have dealt with a more homogeneous environment without the large gaps between pairs of birds that are typical of the spotted owl. The fragmented environment of the spotted owl does not lend itself to expressing dispersal distance in this manner.

Mean vs. median dispersal distances--When straight-line distances are used to express dispersal, should they be averaged? Shields (1982) points out that by averaging the distances, the few long-distance dispersers inflate the mean dispersal distance. This leads to an overestimation of the distance the typical individual moves. He suggests using the median dispersal distance instead. Using our 1983 sample, we calculated both mean and median dispersal distances (table 1) for the categories discussed in determining when dispersal ends. Median dispersal distances were substantially less than the mean, and we feel the median better represented the typical individual's movements.

#### Dispersal-Related Questions

Other dispersal-related questions requiring attention include differential dispersal by sex, population density effects on dispersal distances and success, initiating and terminating factors for dispersal, and yearly variation in dispersal. In a short-term study, some of these questions cannot be adequately addressed. For the spotted owl in particular, an especially important question might be "what effect does fragmentation of the habitat have on dispersal and the foraging behavior, habitat use, and survival of dispersers?" One of the main problems with determining fragmentation effects is devising an appropriate measure of fragmentation. Work with habitat fragmentation presents the investigator with all the problems associated with an uncontrolled experiment: The various arrays of fragmentation were not designed.

If active nests are located in a variety of fragmented regimes, a control area should exist that has little or no fragmentation. Spotted owl movement capabilities seem, unfortunately, to be

great enough to thwart any attempt to utilize existing landscape patterns, even national park or wilderness areas. Dispersing juveniles are likely to pass through several levels of habitat fragmentation, thereby frustrating attempts to differentiate which fragmentation pattern has what effect.

Many investigators have documented that for most birds, females predominate among long-distance dispersers. To test whether or not this is also the case for the spotted owl, one must be able to correctly identify the sex of juveniles. Criteria used in the past to identify the sex of juvenile spotted owls (weight and wing measurements) are not particularly reliable. In a recent paper, Barrows and others (1982) suggest determining sex of spotted owls by inspection of the barring pattern on the middle tail feathers. Of 11 carcasses for which we were able to check tail feathers against an internal examination, the pattern of tail feathers correctly identified the sex of the juvenile in each case. The success of this technique should help answer the differential-dispersal-by-sex question for the spotted owl.

#### SUMMARY

The problems presented here are not new and are common to any study of dispersal. The spotted owl, because of its low density, sporadic reproduction, and small clutch sizes, presents a significant problem to dispersal studies -- small sample size or high cost per unit of data.

The acceptable resolution level of dispersal and measurement of dispersal distances are closely tied to sample size. With a limited sample, it may not be possible to focus only on the successful dispersers. The longer the issue is studied on a continuous basis, the more the above-mentioned problem will be alleviated.

Especially in short-term studies, the major question becomes how much information is enough. There must be a consensus among researchers and managing agencies, such as the State and Federal fish and wildlife agencies, USDA Forest Service, and the Bureau of Land Management, as to what

constitutes an acceptable data set to base management decisions on. The agencies that will employ the information are necessarily responsible for determining the longevity of the studies and the size of the sample.

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THE DEMOGRAPHY AND POPULATION GENETICS OF OWLS,  
WITH SPECIAL REFERENCE TO THE CONSERVATION  
OF THE SPOTTED OWL (*Strix occidentalis*)

George F. Barrowclough and Sadie L. Coats

ABSTRACT: Data are summarized on the density, dispersal, demography, and genetic structure of several species of owls. Life history traits for the majority of these species are such that the effects of variance in reproductive success and overlapping generations act to reduce effective population size with respect to census size by as much as 50 percent. Estimates of effective deme sizes vary over several orders of magnitude; for four of six species, the effective sizes are on the order of  $10^2$  to  $10^3$ . The genetic structure of spotted owl, *Strix occidentalis*, populations in the Pacific Northwest consists of a continuum of neighborhoods isolated by distance from each other. We estimate that currently there are approximately 10 such units, each composed of about 220 effective individuals, in the range of the subspecies *caurina*. A management plan to preserve the species in that region will result in the preservation of a network of habitat patches. The effects such a plan will have on genetic structure and level of inbreeding depend critically on the level of occupancy of the preserved areas. Estimates of this occupancy rate are not available, but a method is outlined to evaluate genetic structure given such estimates or a model of population dynamics. A "best case" example is given along with some recommendations for data that are critically needed for evaluating the actual effects of a spotted owl management plan.

INTRODUCTION

The purpose of this paper is to describe and analyze, to the extent possible, the patterns of demography and population genetics of owls. Special emphasis is placed on the spotted owl, *Strix occidentalis*, a subject of current interest because of concern about the species' status in old-growth forests of the Pacific Northwest.

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It appears likely that much of the old-growth forest that constitutes the prime habitat for the spotted owl will be regularly harvested for timber; thus, the survival of the bird in that part of its range may depend on the maintenance of Spotted Owl Management Areas (SOMAs) in the National Forests of the region. The efficacy of these habitat patches as a mechanism for preserving the spotted owl in the Pacific Northwest will depend not only on the number, size, geographical location and quality of the areas, but also on the demographics (survivorship, fecundity, and dispersal schedules) and genetics of the species (Shaffer 1981). The aspects of the biology of a species can be analyzed using the techniques of population ecology and population genetics. Population ecologists can aid wildlife managers in investigating the way a species' demograph



dispersal patterns, and geographic distribution may interact with environmental factors and ecological perturbations. Models can then be developed for predicting long-term probability of survival. Shaffer (1985) addresses these issues. Geneticists use these same variables and the equations of population genetics to investigate the genetic structure and likely pattern of inbreeding in the population. We address that topic here.

It is widely understood that inbreeding can be detrimental. It can lead to reduced numbers of offspring, poorer quality offspring, and a generally reduced vigor of the individuals in a population. These effects are discussed in Frankel and Soule (1981). A general conclusion of such analyses is that inbreeding, if severe, can lead to inviability of a population and to its eventual extinction. Hence, an important goal of any attempt to maintain a natural population through management must be the monitoring and regulation of inbreeding.

The extent of inbreeding in a population can be measured directly--for instance by using molecular genetics techniques such as electrophoresis (for example, Patton and Feder 1981); however, these methods only yield estimates of the current level of inbreeding. To predict how inbreeding will progress, a model of the genetic structure of the population must be developed. By genetic structure, we refer to the geographic continuity of populations--over what geographic area a population can be considered randomly mating, and how many individuals can be found in that area. The models used to develop guidelines, such as preserving 50 individuals to prevent inbreeding in excess of 1 percent per generation (Frankel and Soule 1981), are based on the assumption of no geographical structure; that is, on complete panmixia of the population. Such an assumption is reasonable for zoos, but not necessarily for a wild population spread over large expanses of a continent.

Researchers concerned with the population dynamic aspects of conservation have explicitly examined the role of geography on the probability of long-term maintenance of a population (see, for example, Shaffer 1985). However, population geneticists concerned with conservation genetics have not devoted equivalent attention to this problem. In this study we begin a first attempt to incorporate this important biological reality into conservation genetic analysis.

Much remains to be learned about the natural and life histories of owls, including the spotted owl. In spite of this lack of complete data, however, management plans are now being developed. To assess whether any particular proposed Spotted Owl Management Plan (SOMP) will be successful over some extended period of time, it is necessary to predict the response of the owls to the details of the plan. This necessitates the rapid development of models for the population dynamics and genetics of spotted owls. Thus, it seems requisite to begin organ-

izing our knowledge of owl demographics and genetics now, even though data are limited. Data from future studies, as well as from projects currently underway, will no doubt refine estimates of parameters and lead to some modifications of results and conclusions; nevertheless, it is equally true that the simple, preliminary results of these analyses and models will identify key life history parameters that require immediate intensive investigation.

Finally, we believe it is important to summarize inferences that currently can be made about the demography and genetics of owls in general and to make these data available to the community of researchers interested in the dynamics and genetics of natural populations.

## METHODS AND RESULTS

Our analysis of the demographics of owls requires the estimation of population density and the distributions of three life history parameters--survivorship, fecundity, and dispersal. From these data, a life table can be constructed; such a table is essential for most approaches to modeling population dynamics. These same data are needed for modeling the genetic structure of a population.

Several models of geographic population structure may be relevant to avian species. The various models and instances of their use in studies of birds have been reviewed by Barrowclough (1980) and Rockwell and Barrowclough (in press). A basic distinction must be made between species that are geographically isolated in colonies or "islands" of habitat, and those that are more or less continuously distributed throughout their range. For the spotted owl, as well as for most other owls, the latter model appears to be more reasonable. For such cases, even though the species' distribution is considered continuous, there is expected to be some genetic differentiation across the range simply because dispersal of young birds, from their natal site to the location where they breed as adults, is finite. Depending on the strength of the tendency for offspring to nest in the vicinity of the site where they were raised (philopatry), it may take several, or even many, generations for genes to "flow" across the range of the species. Continuously distributed populations of birds are therefore said to be "isolated by distance." The genetic structure of such species is modeled by determining the geographical area over which allelic frequencies should be nearly uniform--this requires information about dispersal--and estimating the number of birds in such an area--which requires estimates of density. The "effective population size" ( $N_e$ ) of this area of the total species' range is derived by estimating how such factors as population fluctuations, sex ratio, and life expectancy and fecundity schedules affect the dynamics of genes within the local population.

The effective population size of the local unit (deme) is the number of genetically ideal (randomly mating, discrete generations, Poisson variance of offspring numbers, etc.) individuals that would have evolutionary properties equivalent to those of the actual individuals in the deme with their real, biologically complicated demographic schedules. Once the theoretical effective size of a deme of continuously distributed organisms is known, it is possible to make some predictions about the extent of inbreeding in the population.

The estimation of the genetic structure of natural populations using demographic data, as with any complicated modeling approach, is based on a number of biological and mathematical assumptions. These assumptions are discussed in some detail in Rockwell and Barrowclough (in press).

Calculations. The specific method used to obtain statistics describing the genetic structure of spotted owl populations originated with Dobzhansky and Wright (1943, 1947), who worked on *Drosophila*. The method subsequently was modified for use on avian populations by Barrowclough (1980). We estimate the effective size,  $N_e$ , of current spotted owl demes as the number of randomly mating individuals equivalent to the number of owls actually present in a circle with a radius twice the dispersal distance of juveniles. In summary:

$$N_e = 4\pi \rho \sigma^2 F_K F_{RS} F_{GT} ;$$

where  $\rho$  is the density of spotted owls throughout the area over which dispersal occurs,  $\sigma$  is the root-mean-square dispersal distance for juveniles, and  $F_{RS}$  and  $F_{GT}$  are factors that correct for departures from the random transmission of genes from generation to generation caused by the effects of variation among pairs in reproductive success, and the influence of overlapping generations, respectively.  $F_K$  corrects the geographical size of the deme for the effects of non-normality of the dispersal distribution.

A. Dispersal.--Spotted owls are nocturnal and difficult to study; consequently, quantitative data for the species are just starting to be accumulated, and we were forced to use data and estimates of life history parameters from a number of different sources. Data resulting from radio-tracking juvenile and adult spotted owls in northern California for several years (Gutiérrez and others 1985, unpubl. data <sup>1/</sup>), allow estimation of the dispersal distribution of juveniles and information on survivorship of both juvenile and adult spotted owls.

Table 1--Summary of dispersal distances of juvenile spotted owls, based on radio-tagging within northwestern California

Distance, $d_i$ (km)	0-25	26-50	51-75	76-100
Number, $n$	3	6	3	1

If the distances juveniles moved (between the sites where they were hatched and where they breed as adults) were random with respect to direction and normally distributed with respect to distance, then approximately 87 percent of all genes at a particular point would come from within two standard deviations of the distribution of dispersal distances from that point. Thus, a standard measure of  $N_e$  for continuously distributed organisms is the effective size of the population within a circle of radius  $2\sigma$  (Wright 1969). The root-mean-square dispersal distance,  $\sigma$ , is the standard deviation of juvenile dispersal distances about their nest site (origin);  $\sigma^2$  is the variance of such distances. Dobzhansky and Wright (1947) showed that:

$$\sigma = \sqrt{[(1/2N) \sum d_i^2]};$$

where  $N$  is the total number of juvenile owls studied and  $d_i$  is the distance dispersed by the  $i$ th juvenile. For the study by Gutiérrez and others (1985), the distribution of juvenile dispersal distances is summarized in table 1.  $\sigma$ , computed as described above, was found to be 33.56 km for the 13 radio-tagged juveniles. These data may somewhat underestimate true dispersal distances because some of the owls in the study may have died before finishing their dispersal; additionally, the batteries in some of the transmitters may have failed before dispersal was ended. More dispersal data are needed; at present these are the best data available and suggest that actual dispersal is roughly 30-40 km. It would be desirable to have dispersal distances based on a large sample of birds followed from their birth site to their actual breeding site.

B. Density.--To obtain a realistic estimate of effective deme size, one should have an estimate of density from the same region from which the dispersal distance data were obtained. This is because there is the possibility that density and dispersal may covary. That is, dispersing birds may tend to move further in areas of low density (poor habitat). Data on the density of spotted owls in northern California where the radio-tagging is being performed were obtained. <sup>2/</sup>

<sup>1/</sup>Data on file with R. J. Gutiérrez, Department of Wildlife Management, Humboldt State University, Arcata, CA 95521.

<sup>2/</sup>Data compiled by G. I. Gould, Jr., Wildlife Management Branch, Department of Fish and Game, 1416 Ninth St., Sacramento, CA 95814.



There are approximately 558 territories in the area bounded by the Pacific Ocean on the west, the Oregon border on the north, the northern border of Mendocino County on the south, and a line on the east running north-south through the town of Yreka. It was estimated that 90 percent of the 558 territories were occupied by pairs of owls and the remaining 10 percent by single birds: in 28,990 km<sup>2</sup> of northern, coastal California, there are about 1060 owls, or an approximate density of 0.037 owls per km<sup>2</sup>. This estimate is of average density over good, poor, and completely unsuitable habitat. It is necessary to use this estimate rather than one for strictly good habitat because the dispersal of juveniles takes them through mixes of habitat types, and the geographical area occupied by a single deme of spotted owls will include unsuitable habitat.

**C. Life table.**--A life table is perhaps the most important abstraction required in modeling the population dynamics of a species. It is also needed for modeling population genetics because it provides the information requisite for estimating the effects of delayed breeding and overlapping generations. There are two critical aspects to the estimation of a life table: data are needed on year-to-year survivorship and on fecundity.

1. **Survivorship.**--Survivorship was estimated using the results of the radio-tagging undertaken by Forsman and others (1984) and by Gutiérrez and others (1985). First, for adult spotted owls, it was noted that there were five deaths in 33 owl years of monitoring; this is based on 20 owls that were tracked for periods of 1 to 3 years and six others that were tracked for periods of roughly 4 months. Thus, year-to-year survivorship was approximately 0.85. We assumed that avian lifespans are exponentially distributed (for example, Deevey 1947); survivorship was therefore assumed to be constant for the second year of life on.

Survivorship of juveniles was more difficult to estimate. We again used data from radio-tracking of juveniles in northwestern California. Because of the short timespan over which owls have been tagged, and the high mortality rate, we estimated survivorship separately for each 3-month period of the first year, beginning at the time of fledging. For the first 3 months, 3 out of 13 tagged birds died; this is a period of time when the juveniles are still partially dependent on their parents for food. Survivorship ( $s_x$ ) during this interval was estimated as 10/13, or 0.77. During the next 3-month period, when dispersal occurs and winter begins, 4 of 10 tagged birds died; thus, we took  $s_x$  to be 0.60. For the winter months, 3 of 6 birds apparently died; consequently,  $s_x$  was assumed to be 0.50. No data were available for the last 3 months of the first year of life. During this period of time, spring, prey should become abundant; hence we estimated that the probability of death would be of the order of one-half the rate during the previous 9 months. The average death rate, per 3-month period over

Table 2--Distribution of reproductive success among pairs of spotted owls

No. of fledglings (x)	0	1	2	3	4
No. of pairs (p)	73	16	26	4	0

Source: Forsman and others (1984).

the first 9 months, was 0.38; the average  $s_x$  over this period was 0.62. Thus, for the last 3-month period, we estimated the death rate to be 0.19; this yields an  $s_x$  of 0.81. Consequently, we estimate first year survivorship of spotted owls as (0.77)(0.60)(0.50)(0.81) or 0.19. This estimate has an unknown, but probably substantial, standard error associated with it; it is likely that only about one out of five to one out of ten fledged spotted owls survive their first year.

2. **Fecundity.**--We estimated a mean and a variance of fecundity using the data reported by Forsman and others (1984), which was based on their study of the spotted owl in Oregon. We measured fecundity as the number of fledged, or nearly fledged, offspring observed at a nest. This measure of fecundity conforms to the survivorship period of the life table, which starts at the time of fledging. The numbers of offspring produced by 119 pairs are shown in table 2; a total of 80 young were produced. Thus, each pair produced an average of 0.67 offspring per year. If a 1:1 sex ratio is assumed, then this is equivalent to 0.34 female offspring per female per year. The variance of reproductive success among pairs, computed from the same distribution of fecundities, is:

$$V_{RS} = [\sum px^2 - (\sum px)^2/N]/(N-1) = 0.87;$$

where  $x$  is the number of fledglings produced by a pair,  $p$  is the number of pairs producing that number of fledglings, and  $N$  is the total number of nests observed. We assume spotted owls do not breed their first or second spring; this is generally consistent with life history studies and other, anecdotal information in the literature. It is probably true that some 2-year-olds attempt to breed; also, however, probably not all 3-year-olds do; further study of radio-tagged, known-age birds is warranted.

We stress that the life table for the spotted owl, based on these calculations (table 3), must not be taken as definitive, given the uncertainty associated with much of the data. Nevertheless, it should prove useful as a first approximation in initiating analyses of the dynamics and genetics of the species.

**D. Generation time.**--Age-structure will influence the effective size of a local population. For example, Dobzhansky and Wright (1943) explicitly discuss this problem, and human demographers have devoted much effort to analyses of the magnitude of the effect (for example, Emigh and Pollack 1979). Emigh and Pollack present an algebraic method for



Table 3--Life table for the spotted owl; fecundity is measured as number of female offspring per female

Age (x)	0	1	2	3	4	5	6	7	8	9	10
Survivorship ( $s_x$ )	1.00	0.19	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85
Fecundity ( $b_x$ )	0	0	0	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34

correcting estimates of effective population size for the effects of age-structure, delayed breeding, and overlapping generations.

We have used the life table for spotted owls (table 3) as input to a computer program that calculates the magnitude of this effect. The result is a factor,  $F_{GT}$ , that represents the ratio between effective size and the census number of individuals. For the spotted owl, the result is  $F_{GT} = 0.69$ . The fraction, for this life table, is considerably less than one, indicating an important effect. This is because we have assumed that the density figures are for territorial, but not necessarily breeding, birds; that is, some 1- and 2-year-old birds are present in the population, respond to calling (and so are included in the density estimates), but do not breed. The  $F_{GT}$  factor corrects for the fact that the census density includes prereproductives, and consequently is greater than the number of individuals contributing to the gene pool at any given time. In theory this factor can vary from zero to two; if only reproducing individuals were included in the density figures, then  $F_{GT}$  for this life table would be close to one.

E. Variance in reproductive success.--An underlying assumption of estimates of effective population size is that the variation in reproductive success among pairs of individuals has a Poisson distribution; that is, that the variance of the distribution is equal to its mean. This is an empirical question, however, and it appears that in a number of species, at least of birds, the variance exceeds the mean. Such is the case for the spotted owl, in which our estimate of the mean fecundity is 0.67, and its variance is 0.87 (see above). Again, as with the problem of age-structure, it is possible to compute a correction factor to estimate the effective size of a population with a given distribution of fecundities. The formula is given by Crow and Kimura (1970); the ratio of effective to actual number of individuals is computed as:

$$F_{RS} = x/[x-1+(V_{RS}/x)];$$

where  $x$  is the mean number of fledglings per pair, and  $V_{RS}$  is its variance. For the spotted owl,  $x$  is 0.67,  $V_{RS}$  is 0.87, and  $F_{RS}$  is 0.69.

F. Kurtosis of dispersal.--An additional assumption that requires attention in the computation of effective deme size is that of a normal distribution of juvenile dispersal distances. In fact, as Bateman (1951) points out, dispersal

distance distributions depart to some degree from normal in almost all organisms. (Distributions may be characterized as leptokurtic or platykurtic. In a leptokurtic distribution there are more short- and long-distance dispersers and fewer intermediate-distance dispersers than would be expected in a normal distribution. In a platykurtic distribution there are an excessive number of intermediate distance dispersers over the expectation of a normal distribution, but fewer short- and long-distance dispersers.) The distribution of dispersal distances for the spotted owl (table 1) is slightly platykurtic, with a coefficient of kurtosis of -1.07. Using the above estimate of kurtosis, we estimate a deme of owls, due to this departure from normal dispersal of juveniles, actually occupies an area slightly smaller than the circle of radius  $2\sigma$ . The actual size of this area is reflected in the kurtosis factor,  $F_K$ , computed using the relationship developed by Wright (1969, p. 304-305). For the spotted owl, we obtain an estimate of  $F_K$  of 0.81.

G. Effective deme size.--Given the results of the above analyses, it is possible to compute an estimate of effective population size of a deme or neighborhood using the formula presented earlier:

$$N_e = 4 \pi \rho \sigma^2 F_K F_{RS} F_{GT}.$$

Thus,

$$N_e = 4 \pi (0.04 \text{ km}^{-2}) (33.56 \text{ km})^2 (0.81) (0.69) (0.69) \\ = 218.23.$$

This is an estimate of the effective size of local populations of spotted owls under current conditions.

An additional point is worth noting.  $F_{RS}$  was defined as the ratio of effective size to census size that corrected for the effect of a nonrandom (non-Poisson) contribution of genes from individuals of one generation to the next because of variance among individuals in reproductive success.  $F_{GT}$  was defined as the ratio of effective size to census size that corrected for the fact that generations are not discrete and that prereproductive owls are included in estimates of density. Consequently, the overall ratio of genetical effective population size to census number for spotted owls must be the product of  $F_{RS}$  and  $F_{GT}$ , or 0.48. This implies that to have an effective population size of any particular number of spotted owls, it is necessary to have a census number of

Table 4--Estimates of density for several species of owls

Species	$\rho$ (km <sup>-2</sup> )	Reference
<i>Tyto alba</i>	0.08	Sharrock (1976)
<i>Otus asio</i>	0.30	Craighead and Craighead (1969)
<i>Bubo bubo</i>	0.01	Olsson (1979)
<i>B. virginianus</i>	0.15	Craighead and Craighead (1969)
<i>Strix aluco</i>	0.40	Sharrock (1976)

adults 1/0.48, or 2.10, times as large. For example, an effective population of 500 owls would require a census number of 1,042 owls.

The fact that the effective size of populations is usually substantially less than the census size has now become widely recognized by geneticists and wildlife managers (Frankel and Soule 1981). Thus, the result reported above should not be particularly surprising. Two additional factors with potential effects on this same ratio have not been considered here, but should be kept in mind. First, we have implicitly assumed a 1:1 sex ratio for breeders. If the sex ratio differs from this, then effective size will decrease further. Second, we have assumed that the owl populations are numerically constant and do not fluctuate. If they do fluctuate, about some mean, then the overall  $N_e$  to  $N_c$  ratio will again be reduced and will be biased toward the minimum size (for example, Crow and Kimura 1970, p. 109-110).

**H. Genetic structure and inbreeding.**--Inbreeding is a complex, hierarchical topic. The general, underlying concept concerns the correlation of individual alleles within individuals. That is, in diploid organisms, such as birds, each individual has two copies of each gene. If more than a single allele segregates at a locus in the species, then the probability that the two genes in an individual will be identical can be computed, for a randomly mating population, based on the frequencies of the alleles. If there are departures from random mating, however, then the probability of the two copies of the gene being identical may increase and the individual is said to be inbred; that is, there is a positive correlation of identity of the two copies of a gene within an individual. The departures from random mating may be of two types. First, there may be an increased likelihood of close relatives mating; this is the notion of inbreeding in common usage. It is sometimes identified by the symbol  $F_{IS}$ . Second, if the entire population of the species is not panmictic, but rather is organized into isolated colonies or even more or less continuously distributed neighborhoods (demes), then the copies of the same gene in an individual will be correlated merely due to the geographic structure of the population inhib-

iting the thorough mixing of genotypes in each generation. Here we refer to the magnitude of this effect by the symbol  $F_{ST}$ .

Our computations suggest that the genetic structure of spotted owl populations in the Pacific Northwest is characterized by neighborhoods of approximate effective size of 220 individuals. These demes are not discrete entities, but continuously grade into each other; they each occupy a geographical area of diameter  $4\sigma\sqrt{F_K}$ , or approximately 120 km. Thus, in the range of the subspecies *S. o. caurina* in Washington, Oregon, and California, there are probably on the order of 10 demes. This is a very rough approximation based on geographical distance and area. It is consistent with a current total census population of about 5,000, and a total effective size, summed over demes, of about 2,500. These estimates are probably correct to within a factor of two or so, and will be sufficient for illustrative calculations.

Wright (1969, p. 299-303; see also Rockwell and Barrowclough in press) provides a method for estimating levels of correlation of genes within demes ( $F_{ST}$  inbreeding) that are isolated by distance, relative to the total population. For a series of 10 demes each of size 220,  $F_{ST}$  is estimated to be about 0.007.

#### DEMOGRAPHY AND GENETICS OF SELECTED SPECIES OF OWLS

We examined literature on life history, ecology, and behavior of birds to obtain comparative results for other species of owls. This survey was made partly to ascertain whether our estimates of spotted owl parameters were reasonable, but also to explore the demography and genetics of a number of species of an avian order and make the results available to ornithologists and population ecologists.

We found sufficient data to compute estimates of life tables and effective deme sizes for five additional species of owls: *Tyto alba*, *Otus asio*, *Bubo virginianus*, *B. bubo*, and *Strix aluco*. Of necessity, data from more than one study had to be combined in the analysis of some of these species. Where possible, data used for a species were all from the same geographic region. Data for *Tyto alba*, the barn owl, are from England, except for fecundity and survivorship values which come from studies in the United States. Data for *Otus asio*, the eastern screech-owl, come from northern Ohio and southern Michigan. Data for *Bubo bubo*, the Old World eagle owl, derive from studies in southeastern Sweden, and Germany and adjacent northern Austria. Density figures for *Bubo virginianus*, the great horned owl, come from southern Michigan; the data for productivity, dispersal, and survivorship are from birds breeding in Saskatchewan. All data for *Strix aluco*, the tawny owl, are from near Oxford,

Table 5--Distribution of dispersal distances for selected species of owls

Species	Distance and number dispersing <sup>1/</sup>										Reference
<i>Tyto alba</i>	x	5	30	75	150	250					Bunn and others (1982)
	f(x)	98	68	9	8	1					
<i>Otus asio</i>	x	8	24	40	56	105	185	233	298		Van Camp and Henny (1975)
	f(x)	25	21	3	2	1	1	1	1		
<i>Bubo bubo</i>	x	25	50	75							Olsson (1979)
	f(x)	8	5	3							
<i>B. virginianus</i>	x	5	26	81	185	315	710	908	1062		Houston (1978)
	f(x)	18	17	23	11	3	4	3	2		
<i>Strix aluco</i>	x	0.7	1.5	3.5	7.2	20					Southern (1970)
	f(x)	3	1	2	1	2					

<sup>1/</sup>f(x) is the number of individuals banded as nestlings and recovered, when old enough to breed or hold a territory, x kilometers from their nestsite.

Table 6--Mean and variance of reproductive success among pairs in selected species of owls

Species	Number of young fledged per pair							x	V <sub>RS</sub>	Reference
	0	1	2	3	4	5	6			
<i>Tyto alba</i>	31	11	18	22	22	10	1	2.23	3.02	Bunn and others (1982)
<i>Bubo bubo</i>	22	10	8	7	0	0	0	1.00	1.26	Frey (1973)
<i>B. virginianus</i>	82	78	121	84	6	0	0	1.61	1.23	Henny (1972)
<i>Strix aluco</i> <sup>1/</sup>	8	3	2	3	1	0	0	1.18	1.90	Southern (1970)

<sup>1/</sup>Data from 1947 study year.

England, except the density figures, which are an average over all of England, Scotland, and Wales.

Data for density, dispersal, and reproduction are listed, with their sources, in tables 4, 5, and 6. Tabulated values were mostly taken directly from the literature, but in some cases estimates of requisite parameters were not available and were calculated using published information.  $\sigma$ ,  $V_{RS}$ , and factors  $F_K$  and  $F_{RS}$  were computed as for the spotted owl. Dispersal distances in table 5 are not uniform across species because of the way that data are reported in the original literature. The values shown are the midpoints of the reported intervals. Data for among-pair variation in number of fledglings produced by *Otus asio* were lacking, so the mean of the other five  $V_{RS}$  estimates was used for that species.

Estimates of life tables for the five species of owls are shown in table 7. All are arbitrarily truncated at 10 years. The estimates of fecundity are based on data in table 6 except for *Otus asio* and *Strix aluco*; a 1:1 sex ratio is assumed and  $b_x$  is given as female offspring per female. For *Otus*, the complete life table is that computed by Ricklefs (1983). For *Strix*, the data in table 6 are for a single year, 1947, of

Southern's study (1970). The estimate of  $b_x$  in table 7 represents an average for the tawny owl over 13 study years. To compute year-to-year survivorship, we computed ratios of returns of banded birds from consecutive years. Juveniles were treated as a separate class. In cases for which adequate returns were available, first year birds were also treated separately. These life tables are all rough approximations, but are adequate for the calculation of  $F_{GT}$ , which was their intended purpose.

Table 8 contains estimates of effective deme sizes and several other parameters relevant to the genetics of natural populations. The estimates were computed as described above for the spotted owl. There is substantial variation of the estimates of  $N_e$  among species. The principal factors contributing to the variation appear to be dispersal distances, density, and the factor reflecting variance in reproductive success among pairs ( $F_{RS}$ ). The results for the great horned owl indicate an exceptionally large value of  $N_e$ ; this reflects the estimate of dispersal that is an order of magnitude greater than those for the other species. The sample sizes in Houston's (1978) study were not small; however, the result is influenced by a few very long distance dispersers. Thus, the estimate is probably a bit on the high side. For example, if



Table 7--Life tables for selected species of owls

Species		Age (x)							Reference
		0	1	2	3	4	5	6-10	
<i>Tyto alba</i>	$s_x$ <sup>1/</sup>	0.35	0.57	0.63	0.63	0.63	0.63	0.63	Stewart (1952)
	$b_x$ <sup>2/</sup>	6.00	1.12	1.12	1.12	1.12	1.12	1.12	Bunn and others (1982), Henny (1969)
<i>Otus asio</i>	$s_x$	0.31	0.59	0.63	0.67	0.75	0.75	0.75	Ricklefs (1983)
	$b_x$	0.00	1.04	1.30	1.30	1.30	1.30	1.30	Ricklefs (1983)
<i>Bubo bubo</i>	$s_x$	0.44	0.67	0.67	0.67	0.67	0.67	0.67	Rockenbach (1978)
	$b_x$	0.00	0.00	0.50	0.50	0.50	0.50	0.50	Frey (1973)
<i>B. virginianus</i>	$s_x$	0.42	0.56	0.67	0.67	0.67	0.67	0.67	Houston (1976)
	$b_x$	0.00	0.00	0.80	0.80	0.80	0.80	0.80	Henny (1972)
<i>Strix aluco</i>	$s_x$	0.47	0.79	0.82	0.82	0.82	0.82	0.82	Southern (1970)
	$b_x$	0.00	0.35	0.35	0.35	0.35	0.35	0.35	Southern (1970)

<sup>1/</sup>Year-to-year probability of survival.

<sup>2/</sup>Female offspring per female per year.

dispersal and density covary (that is, if dispersal distances are greater for owls that travel through unsuitable habitat), then the estimate of  $N_e$  would be exaggerated because, for this species, our estimate of density is for an area of farms and eastern deciduous woodland (that is, generally good habitat).

An important point evident in table 8 is that the results for the spotted owl do not stand out or otherwise seem unreasonable compared with the other five species. Additionally, with the exception of *Bubo virginianus*, the values of  $N_e$  for these owls, including *S. occidentalis*, fall in the same range as the values computed for an assortment of passerine birds by Barrowclough (1980). As pointed out by Barrowclough and Shields (1984), such values are also in general agreement with the results of karyological and electrophoretic analyses.

A final comment concerns the influence of kurtosis of the dispersal distribution and the pair-to-pair variance in reproductive success on the calculation of deme size. Neither of these factors have previously been computed for analyses of  $N_e$  for birds. Shields (1981), for example, suggests that correcting for kurtosis of the dispersal distribution might result in a significant reduction in the estimate of  $N_e$ . This seems not to be the case for these owl species; the size of the effect varies from 0 to at most 25 percent. The reproductive variance factor ( $F_{RS}$ ) is of greater importance, ranging from about 0.6 to 1.2. No generalization seems possible concerning this effect; its influence may be to decrease, increase, or leave unchanged an estimate of  $N_e$  derived in the absence of data requisite for estimating the factor.

#### EFFECTS OF THE SPOTTED OWL MANAGEMENT PLAN

A major effect of managing National Forest land in the Pacific Northwest for timber harvesting is a reduction of suitable foraging and nesting habitat for the spotted owl. The object of the spotted owl management plans developed by the USDA Forest Service is to preserve a gridwork of suitable habitat patches for the owls (SOMAs) in the National Forests of California, Oregon, and Washington. Although the precise details of the overall SOMP are not clear, it appears that about 800 to 1,000 SOMAs will be set aside for pairs of spotted owls in the 3-State area. Unfortunately, a complete estimate of the effects a SOMP will have on the genetics of spotted owls would require a model of the population dynamics of the owl/habitat patch interaction under the plan. Because such a model is not available, we must limit our analysis to the genetical effects of the SOMP under unrealistic "best case" conditions, and can only outline an approach to the analysis of actual future conditions.

**Best Case.** The best case, from a genetical point of view, would be a condition in which all the SOMAs were used by breeding pairs; that is, if occupancy were 100 percent. In reality, of course, this is not possible as a long-term equilibrium situation because individual owls will eventually die and, depending on the nature of age-structure and patterns of dispersal through patchy habitat, it will take a finite time for any patch to become reoccupied by a breeding pair. Nevertheless, if the best case of 100 percent occupancy were realized, then there would be about 850 pairs of owls spread over the Pacific Northwest.

Table 8--Estimates of population genetics parameters<sup>1/</sup> for selected species of owls

Species	$\sigma$ (km)	$\rho$ (km <sup>-2</sup> )	$N_C$	$F_K$	$F_{RS}$	$F_{GT}$	$N_e$
<i>Tyto alba</i>	31.14	0.08	974.85	0.93	0.86	0.87	678.33
<i>Otus asio</i>	44.03	0.30	7308.50	0.90	0.84 <sup>2/</sup>	0.78	4309.68
<i>Bubo bubo</i>	32.78	0.01	135.03	0.75	0.79	1.30	104.01
<i>B. virginianus</i>	216.35	0.15	88229.72	0.96	1.17	0.67	66396.75
<i>Strix aluco</i>	6.99	0.40	245.60	1.00	0.66	0.72	116.71
<i>S. occidentalis</i>	33.56	0.04	566.13	0.81	0.69	0.69	218.23

<sup>1/</sup>Root-mean-square dispersal distance ( $\sigma$ ), density ( $\rho$ ), census number per neighborhood ( $N_C$ ), correction factors for kurtosis ( $F_K$ ), variance in reproductive success ( $F_{RS}$ ), and generation time ( $F_{GT}$ ), and effective population number per neighborhood ( $N_e$ ).

<sup>2/</sup>Mean for other 5 species (data for *Otus asio* not available).

At present, the data from California and Oregon suggest that the density of owls in the Coast Ranges and the Cascade Range is of the order of 0.03 to 0.04 owls per km<sup>2</sup>. This is an average density over prime, fair, and unusable habitat. A management plan with approximately 500 SOMAs in Oregon plus Washington and about 400 in California would translate into 1,800 adults in approximately 110,000 km<sup>2</sup> of equivalent area. Thus, the overall density of the birds would fall to 0.016 owls per km<sup>2</sup>. If life history traits of the birds were unaltered by the patchy habitat, then effective size would decrease correspondingly from the current value of about 220. In particular, we can estimate that  $N_e$ , per local deme, would be reduced to:

$$4 \pi (0.016)(33.56)^2 0.81(0.69)0.69 = 87.33.$$

Inbreeding at two levels must be considered in determining the effects the best case scenario of the management plan would have on the genetic structure of the spotted owl. First, the effects on the rate of loss of variation and increase of inbreeding over the entire range must be found and, second, the change in local inbreeding,  $F_{st}$ , caused by reduction in the effective size of local neighborhoods must be computed. With regard to the first problem, there is a question of whether the entire population can be considered panmictic for purposes of calculating the rate of increase of inbreeding. Unfortunately, that problem appears not to be well studied theoretically for realistic models. For example, the generalization that a series of populations can be considered panmictic if they exchange one or more individuals per generation is explicitly based on an "island" model of population structure; it does not apply to more biologically reasonable "stepping-stone" and "isolation-by-distance" models. Maruyama (1977) reports, however, that for a two-dimensional, continuous space model the entire population can be considered panmictic if  $\rho \sigma^2 > 1$ . For this case,  $\rho \sigma^2 = 0.016(33.56)^2$  is of the order of 20, so the roughly 10 demes each of effective size

85 can be considered a single panmictic population of size 850 for computation of loss of variability. Expected overall inbreeding will therefore increase at a rate of  $1/2N_e$ , or 0.0006 per generation. (If the spotted owl distribution is considered one-dimensional, essentially the same result is obtained for the "best case.")

In order to compute how  $F_{st}$  will change with the implementation of the management plan, we compute the expected value, again using the procedure of Wright (1969), for a series of 10 demes each of size 85. For such a case,  $F_{st}$  is 0.017. This, however, is not a per generation increase of inbreeding of demes relative to the entire population: it is the equilibrium level. Wright (1969) indicated that the amount of time required to achieve this equilibrium is of the order of magnitude of the total number of neighborhoods in the population. Consequently, local correlation of genes within individuals is expected to rise from the current estimated level of 0.007 to 0.016 over a period of about 10 generations.

Under the "best case" situation, the management plan would result in an increase in local inbreeding, relative to total variation, of about 1 percent, and a slow loss of overall variability, at a rate probably of the same order as replenishment by mutation (Franklin 1980).

#### A GENERAL METHOD FOR ASSESSING GENETIC EFFECTS OF A MANAGEMENT PLAN

The method outlined above should enable an interested researcher to compute the genetic effects of any particular management plan, given a set of estimates of the key variables. The particular calculations are for the unrealistic case of 100 percent occupancy of the management

sites. A more realistic result could be obtained if estimates of mean occupancy rate were available. An estimate of density based on the anticipated mean occupancy, if used in the above equations, would yield an average value for the effective size of the managed population; from this, estimates of inbreeding could be obtained easily. Such an exercise ought to be performed before any management plan is implemented.

A more sophisticated but more useful way of realistically evaluating the genetic effects of a management plan requires the development of a model of the population dynamics of the species including, especially, a model of death and recolonization of the habitat patches or SOMAs. Repeated simulation of such a stochastic model would yield predictions of the time course of effective deme size for the owl-habitat system. From this a probability distribution of inbreeding rates could be obtained.

#### RECOMMENDATIONS

The statistics that have been recommended for management purposes and discussed by Frankel and Soulé (1981)--total effective population sizes of 50 individuals for short-term preservation, 500 for long-term, and a maximum of 1 percent inbreeding per generation--must be regarded as only guidelines. The models on which they are based are quite simplistic. Nevertheless, they must be taken as the most reasonable minimal goal in the absence of more specific analysis of the needs of any given species with its own population ecology, age structure, and social and mating system.

Our analysis of the "best case" scenario for the management plan for spotted owls outlines a method for evaluating the effects of any management plan, given estimates of several important parameters. Estimates of these are now critically needed, therefore we believe that it is imperative to:

1. Devote research effort to investigating those key aspects of the spotted owl's biology that

are relevant to the development of a model for the dynamics of the owl's population.

2. Develop such a model and use it to investigate both the long-term stability of the owl's population under various SOMPs and the probable genetic effects of the SOMP.

3. Proceed with extreme caution in timber harvesting until the above results are obtained.

Our particular recommendations in regard to the first item are:

1. To study the effects of patch size and habitat composition on occupancy and fecundity.

2. To study intensively the dispersal of juveniles to get information on whether (and with what probability) isolated patches of suitable habitat are found.

3. To estimate, by using surveys, the current occupancy rates of isolated patches of good habitat.

Additionally, more data on fecundity, adult and juvenile survivorship, and dispersal are needed to confirm or modify our preliminary estimates. Finally, blood or tissue samples should be taken from 20 to 25 juveniles at a couple geographical locations during routine banding or radio-tagging activities for later electrophoresis. The laboratory results could be used to assess current levels of inbreeding ( $F_{is}$  and  $F_{st}$ ) and genic heterozygosity of the species.

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THE METAPOPULATION AND SPECIES CONSERVATION:  
THE SPECIAL CASE OF THE NORTHERN SPOTTED OWL

Mark L. Shaffer

**ABSTRACT:** The conservation of patchily distributed species presents a complex problem for land-use planning and wildlife management. A new paradigm of population structure will be necessary to understand the extinction-persistence dynamics of such species both for site-specific and regional conservation efforts. The metapopulation model provides a beginning conceptual framework for solving this problem.

The model is reviewed in light of the problem of avoiding stochastic extinctions and illustrated with the current problem of conserving the northern spotted owl (*Strix occidentalis caurina*) in the Pacific Northwest. Major theoretical and empirical research needs are identified both for the applicability of the metapopulation model in general and for the northern spotted owl in particular.

INTRODUCTION

The equilibrium theory of island biogeography (MacArthur and Wilson 1967) has had a significant impact on biogeography, population ecology, community ecology and conservation. Currently, controversy persists on the validity of the theory (Gilbert 1980, Simberloff 1983) and the applicability of principles derived from the theory for the design of nature reserves (Margules and others 1982, Simberloff 1983). Irrespective of the outcome of these controversies, the theory, and the studies it has spawned, have led to three realizations of fundamental and continuing importance to conservation:

1. Local extinctions and colonizations, in ecological time, may be common events.
2. Extinctions and colonizations may, in many cases, be the products of stochastic events.

3. The simple geometric variables of habitat area and interhabitat distance, through their relationship with stochastic events, may be important determinants of the rate of local extinctions and colonizations.

These realizations raise key issues that must be addressed if certain conservation efforts are to be successful. The importance of these realizations does not hinge on the validity of any particular theory of the interplay of the extinction and colonization processes. The fact that equilibrium theory remains inadequately validated as a general description of nature simply means that the relationship of the extinction and colonization processes remains unclear, particularly their relative frequencies and subsequent balance for various scales of time, size, and population structure. In fact, some of the studies necessary for conservationists to deal effectively with the issues raised by these realizations will help in further validating, refuting, or refining equilibrium theory.

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To date, most efforts to apply equilibrium theory to conservation have involved postulating principles on the size, configuration, and dispersion of nature reserves that will maximize the species



richness they contain and minimize the loss of species over time (for a review, see Margules and others 1982). An equally challenging problem is that of assessing the probabilities of persistence for species that are patchily distributed and whose patchwork of habitat is undergoing alteration. An example is an old-growth-dependent species in a National Forest where the natural successional mosaic is undergoing alteration due to both natural disturbance and resource management activities such as timber harvest. Here the question is how the probability of species persistence on the forest responds to various regimes of patchwork alteration (that is, reduction in either the number or size of habitat patches and their increased isolation, or both). Managers need to know how any old-growth stands of what size and what distance from similar neighbors must be maintained to assure the persistence of the species in the forest to meet some acceptable management criterion (for example, 95 percent probability of persistence on the forest for one successional or rotational cycle). The solution to this complex problem relies on various areas of biological and ecological knowledge that are not yet fully developed theoretically, empirically, or experimentally. These areas include stochastic population dynamics and the roles of temporal and spatial environmental heterogeneity, dispersal, and genetic diversity in population regulation and, hence, persistence. The tone of this paper is, therefore, necessarily speculative. My goal is to establish a frame of reference, identify key processes and variables, and point to potentially fruitful approaches for further work in this important area. My specific objectives are:

- Reiterate the probabilistic component of extinction and, hence, conservation.

- Introduce conservationists to the concept of the metapopulation as a basic frame of reference for conserving patchily distributed species.

- Review a simple model of metapopulation dynamics.

- Outline the potential relationships of the factors affecting metapopulation extinction dynamics and the spatial configuration of habitat.

- Examine the implications of these relationships for conservation of the northern spotted owl (*Strix occidentalis caurina*) in terms of both management actions and research needs.

## THE STOCHASTIC COMPONENT OF EXTINCTION

Populations may go extinct from a variety of factors, but almost any factor can operate in two very different ways. Systematic pressures, despite temporal or geographic variation, show a significant trend over time that negatively impacts the population. Long-term climatic changes are one example. In such a situation, the size of the population bears only on the length of time the population persists, but extinction is a foregone conclusion provided the trend does not change. Stochastic perturbations show no significant trend with time but still may force a population

to extinction if sufficiently frequent or severe. Drastic, intermittent variations in climate are an example of this mode of extinction. In this case, the population's size and distribution may be critical determinants of its persistence through the temporary period of unfavorable conditions.

Once systematic pressures have been identified and solutions instituted for a species in jeopardy, the question of stochastic perturbations remains. One essential goal for effective conservation is the minimization of extinctions due to stochastic perturbations. The northern spotted owl provides an example of the relationship of these two modes of extinction. The species is currently of concern because of its apparent dependence on old-growth coniferous forests (Forsman and others 1984, Gutiérrez and others 1983), a habitat which has steadily declined over the years due principally to timber harvest. Further habitat declines are anticipated due to the high economic value of the timber that provides suitable habitat. Determining that habitat preservation is critical to the species survival is the answer to the systematic pressure threatening this species. But determining how much habitat to preserve and how it is distributed must address the species' viability in the face of the stochastic perturbations to which it may be subject. Land is a precious resource. So is biotic diversity. When the conservation of a species conflicts with alternative land uses, the first question to arise is what is the minimum land area necessary to achieve conservation. Given that localized extinctions are, in part, the results of stochastic events, and the probability of such extinctions increases with time and decreasing population size, determining the amount of land necessary to achieve the conservation of a species must address three key issues:

1. The types of stochastic perturbations to be anticipated.
2. The time frame to use in conservation planning.
3. The degree of security sought for the unit being conserved.

These issues are addressed for a single, isolated population in an earlier paper (Shaffer 1981). The northern spotted owl represents a different problem--a species distributed on a patchwork of habitat. A new perspective on population structure is necessary to deal with the conservation of such species.

## THE METAPOPOPULATION

### The Metapopulation Concept

Most species are patchily distributed and can be viewed as a population of populations (Levins 1970) or a metapopulation (Wilson 1975). Wilson (1975) provides a metaphorical description of the metapopulation as "...a nexus of patches, each patch winking into life as a population colonizes it and winking out again as extinction occurs. At equi-



Figure 1.--A hypothetical metapopulation at two different time steps: (A)  $T=1$ ; (B)  $T=2$ .

librium the rate of winking and the number of occupied sites are constant, despite the fact that the pattern of occupancy is constantly shifting" (fig. 1). For such a patchily distributed species, global extinction is equivalent to its extinction on all patches. Effective conservation of such species thus requires an understanding of the processes of local extinction and colonization and the factors affecting these processes.

#### Levins' Model

Levins (1970) provides an initial treatment of metapopulation dynamics (table 1). His model considers three parameters: the proportion of patches occupied by populations at some particular time ( $N_x$ ), the proportion receiving immigrants (prospective colonizers) in an instant of time ( $m$ ), and the proportion of patches whose populations are going extinct in an instant of time ( $\bar{e}$ ). The model states that the Change in occupancy of patches over time is a function of the rates of immigration and extinction.

Levin's model, although a general one, is oversimplified. It is formulated in continuous time. It assumes either equal size patches or no relationship between patch size, population size and extinction

probabilities. Nevertheless, the model provides a conceptual beginning for a more detailed consideration of the determinants of metapopulation persistence.

Table 1--Levins (1970) model of metapopulation dynamics

Let:

$N_x(t)$  = proportion of patches occupied by populations at time

$m$  = proportion of patches receiving migrants in an instant of time (whether occupied or not).

$\bar{e}$  = proportion of populations becoming extinct in an instant of time.

Then:

$$dN_x/dt = mN_x(1-N_x) - \bar{e}N_x \quad (1)$$

and, at equilibrium:

$$\hat{N}_x = 1 - \bar{e}/m \quad (2)$$

Levins' (1970) analysis of this model reveals several important findings. First, for the metapopulation to persist, the proportion of patches receiving immigrants (or the rate of immigration,  $m$ ) must exceed the rate of extinction ( $e$ ). If the equilibrium proportion of occupied patches ( $\hat{N}_x$ ) is close to 1, a change in extinction rate has relatively little effect on  $\hat{N}_x$ . If  $\hat{N}_x$  is small, however,  $\hat{N}_x$  is more sensitive to changes in extinction rate. When extinction rate shows random variation through time the immigration rate must exceed the extinction rate by more than the variance of the extinction rate for the species to persist (that is,  $m - \bar{e} > \sigma_e^2$ ). If the variation in extinction rate is autocorrelated, the persistence of the metapopulation is further reduced.

If the immigration rate ( $m$ ) is large, then the persistence of the metapopulation is very sensitive to changes in  $m$ . Different species are likely to have different distributions of immigration probabilities (compare passive, wind-dispersed seeds to actively dispersing birds). Levins (1970) and MacArthur and Wilson (1967) argue that an exponential decline of dispersing individuals with distance is a reasonable qualitative description for passive dispersing species. In this case, a change that doubles the distance between patches will square the immigration rate and will have a greater effect on the chances of persistence than would doubling the extinction rate. Consequently, increased patch separation, as this affects dispersal probabilities, may be the limiting factor in determining metapopulation persistence for passively dispersing species. Though based on a simplistic model, this is an important finding. In Levins' words, it:

...forces us to change our notion of suitable habitat. If there is always a finite probability of extinction of a local population even in the best of circumstances, a region will be suitable or unsuitable depending on the density of appropriate sites and a species will fail to survive even if its optimal habitat is present.

Thus, habitat (patch) density may be as fundamental to conservation as habitat quality and management actions that reduce habitat density may lead to the regional extinction of a species even if habitat of suitable quality remains. An important management corollary of this result is that effective conservation of patchily distributed species may require the preservation of suitable but intermittently, perhaps currently, unoccupied habitat.

The minimal objective of metapopulation conservation is simply its continued existence; that is, persistence in one or more patches ( $N_x > 0$ ). This requires maintaining an immigration rate greater than the extinction rate ( $m > e$ ). This can be achieved either by increasing the immigration rate or decreasing the extinction rate. Aside from the foregoing consideration of the effects of interpatch distance on immigration, Levins' model does not explicitly incorporate the spatial dimensionality of the metapopulation in terms of patch number or size and their effects on immigration

or extinction rates. Yet, if population size correlates with area, probability theory would indicate that patch number is an important consideration for both immigration and extinction rates; and both probability theory and empirical studies (Gilpin and Diamond 1981, Jones and Diamond 1976, Simberloff 1976) indicate that patch size should be an important determinant of extinction rate. To go further requires incorporation of this spatial dimensionality and an examination of its effects on metapopulation persistence. First, it is necessary to more clearly define the specific objectives of metapopulation conservation.

#### Metapopulation Structure and Conservation Objectives

From a conservation standpoint, the interest is in estimating certain probabilities of the extinction-persistence of the metapopulation or parts thereof. These probabilities may be defined as shown in table 2 for a metapopulation starting from saturation (that is, all patches occupied).

Table 2--Definitions and relationships of metapopulation probabilities

Let:

$e_i$  = probability of extinction on patch  $i$ ;

$p_i$  = probability of persistence on patch  $i$ ;

$E$  = probability of extinction everywhere (that is, all patches);

$P$  = probability of persistence everywhere;

$e_x$  = probability of extinction somewhere (that is,  $\geq 1$  patch);

$p_x$  = probability of persistence somewhere.

Then:

$$e_i = 1 - p_i$$

$$p_i = 1 - e_i$$

$$E = \sum_{i=1}^N e_i$$

$$P = \sum_{i=1}^N p_i$$

$$e_x = 1 - P = 1 - \sum_{i=1}^N p_i$$

$$p_x = 1 - E = 1 - \sum_{i=1}^N e_i$$

If the metapopulation under consideration is a closed system (that is, it is not connected to or embedded in another metapopulation) and patches are fixed, permanent, and independent with regard to stochastic events, then these extinction-persistence probabilities may be calculated as shown in table 2. For conservation purposes interest is most likely to be in determining the



probabilities of (1) extinction in certain patches ( $e_i$ ), (2) over all patches ( $E$ ), or (3) of persistence of the species somewhere within the patchwork ( $p_{\infty}$ ,  $x \geq 1$ ).

Clearly, once the site-specific extinction probabilities ( $e_i$ 's) are estimated all other probabilities can be calculated. Equally clear is that we generally do not know, nor can we expect to estimate, site-specific extinction probabilities over a short time with much meaning for long-term planning (but see Gilpin and Diamond 1981). Moreover, estimating site-specific extinction probabilities for an existing metapopulation configuration does not necessarily allow prediction of the  $e_i$  schedule that will pertain to a new metapopulation configuration, because this value is, in part, a function of the configuration in which it is estimated. Even on a qualitative basis these relationships raise an important management issue: the specific objective of metapopulation conservation. Is the objective to assure the persistence of the species:

1. On a particular patch or set of patches (minimize  $e_i$  and/or  $e_{\phi}$ , etc.)?
2. On all patches (minimize  $e_i$ 's and  $E$ )?
3. On at least one or some preselected percentage of unspecified patches (maximize  $p_{\infty}$ ,  $x \geq 1$ )?

In the absence of an answer to this question, no definition of a minimum patchwork can be offered. The answer chosen may make a difference in which land-use pattern(s) will be acceptable.

In the remainder of this paper, the focus will be on minimization of site-specific ( $e_i$ ) and overall ( $E$ ) extinction probabilities as the conservation objective probabilities. This is an arbitrary choice. Because  $E = \sum_{i=1}^N e_i$ , anything reducing site-specific extinction probabilities will automatically reduce overall extinction probabilities, but the chances of overall extinction may be reduced simply by increasing patch number ( $N$ ). Though considering both site-specific and overall extinction probabilities may introduce a certain redundancy, the factors affecting these probabilities can operate at different levels of metapopulation structure. The discussion will be more comprehensive if both types of probabilities are included. It should also be useful to contrast site-specific conservation versus patchwork conservation.

It should be noted that because  $p_{\infty} = 1 - E$ , minimizing the overall extinction probability automatically maximizes the probability of persistence somewhere, which will usually be the real objective of metapopulation conservation.

#### METAPOPULATION CONFIGURATION AND STOCHASTIC EXTINCTION DYNAMICS

There are four categories of stochastic perturbations that may be factors in the extinction of a population (Shaffer 1981):

1. Demographic stochasticity caused by chance events in the survival and reproduction of a finite number of individuals.
2. Environmental stochasticity resulting from temporal variation of habitat and niche parameters such as weather, food supply, predators, etc.
3. Natural catastrophes such as floods, fires, hurricanes, etc.
4. Genetic stochasticity, or changes in gene frequencies with negative effects on demographic parameters resulting from founder effect, random fixation, or inbreeding.

It is reasonable to reduce this organization to three categories by recognizing natural catastrophes as merely an extreme form of environmental stochasticity. One important distinction within this new composite categorization is that of stochastic events that are contagious by nature (for example, epizootics). It is anticipated that such events may have spatial dynamics that differ from noncontagious events such as floods, drought, etc. Ruediger (1985) presents examples of these phenomena relevant to the northern spotted owl.

All these categories of stochastic perturbations increase in importance with decreasing population size. Moreover, they are likely to interact, as for example an environmental perturbation that reduces population size over time to the point where inbreeding depression may become a factor by negatively impacting the demographic parameters of survival and fecundity. Though increased attention has recently been focused on the importance of genetic stochasticity (Frankel and Soule 1981, Schoenwald-Cox, and others 1983, Soulé and Wilcox 1980), there is still no theoretical or empirical guidance on which category of stochastic perturbation sets the lower limit to population viability. This may well vary from one type of population to another (for example, density-independent populations with nonoverlapping generations vs. density-dependent populations with age structure).

To better understand how the geometric distribution of habitat may affect metapopulation extinction dynamics, it is necessary to consider how changes in the metapopulation configuration variables (that is, patch number, size, and isolation) may affect the objective probabilities ( $e_i$ ,  $E$ ) caused by the various categories of stochastic perturbations (demographic, environmental, genetic). Because habitat management chiefly controls the metapopulation configuration variables, this discussion is organized with each variable considered separately. The discussion is condensed in table 3 where, for a particular change in each configuration variable, the expected change in site-specific and overall extinction probabilities caused by various stochastic perturbations acting through various conditions, is given. This discussion assumes a strong, positive correlation between habitat area and population size.

Table 3--Expected changes in site-specific ( $e_i$ ) and overall ( $E$ ) extinction probabilities with changes in population configuration variables caused by various types of stochastic perturbations.

Population configuration variable	Change	Objective probability	Change	Caused by	Acting through
Patch #	↑	$e_i$	↓	demographic stochasticity	sources of immigrants
			↓	noncontagious stochastic events	sources of immigrants
			↑↓	contagious stochastic events	sites for initiation, sources of immigrants
	↑	$E$	↓	genetic stochasticity	sources of immigrants
			↑↓	demographic stochasticity	number of realizations, sources of immigrants
			↑↓	noncontagious stochastic events	environmental correlation, sources of immigrants
			↑↓	contagious stochastic events	sites for initiation, sources of immigrants
			↑↓	genetic stochasticity	number of realizations, sources of immigrants
Patch Size	↑	$e_i$	↑↓	demographic stochasticity	inherent resilience, number of immigrants
			↑↓	noncontagious stochastic events	
			↑↓	contagious stochastic events	
			↑↓	genetic stochasticity	
	↑	$E$	↑↓	demographic stochasticity	inherent resilience, number of immigrants
			↑↓	noncontagious stochastic events	
			↑↓	contagious stochastic events	
			↑↓	genetic stochasticity	
Isolation	↑	$e_i$	↑	demographic stochasticity	distance for immigrants
			↑	noncontagious stochastic events	distance for immigrants
			↑↑	contagious stochastic events	distance for infectives, distance for immigrants
	↑	$E$	↑	genetic stochasticity	distance for immigrants
			↑	demographic stochasticity	distance for immigrants
			↑↓	noncontagious stochastic events	distance for immigrants, environmental correlation
			↑↑	contagious stochastic events	distance for infectives, distance for immigrants
			↑	genetic stochasticity	distance for immigrants

Further, the entire discussion is intuitive and is based on common sense expectations. Unless otherwise stated, all cause-effect statements come with the caveat of, "all else being equal." This is not intended as a comprehensive, exhaustive discussion, but rather as an indication of the major relationships and potential complexity of the interplay between various stochastic perturbations and metapopulation configurations.

#### Patch Number

Increasing the number of patches should decrease both site-specific ( $e_i$ ) and overall ( $E$ ) extinction probabilities for two reasons. First,  $e_i$  should be reduced because more patches constitute more sources of immigrants that may bolster a patch population temporarily failing because of demographic, environmental, or genetic stochasticity. This is the so-called "rescue effect" (Brown and Odric-Brown 1977). This phenomenon deserves much more theoretical and empirical attention.

Second, because the overall extinction probability is equal to the product of all site-specific extinction probabilities ( $E = \prod_{i=1}^N e_i$ ; if  $e_i$ 's are independent), the chances of overall extinction can be reduced simply by adding to patch number even if the site-specific extinction probabilities remain unchanged. The larger site-specific extinction probabilities are, however, the more patches must be added to achieve a certain specified overall extinction probability. For example, if  $e_1 = e_2 = e_3$ , etc., and the objective is to achieve  $E \leq 0.10$ , then for  $e_i = 0.5$ ,  $N$  must be  $\geq 4$ . If  $e_i = 0.9$ , however,  $N$  must be  $\geq 22$  to achieve the specified level of  $E$ . The key point here is the extent to which patches are independent with respect to the stochastic perturbations affecting populations. The greater this independence, the greater the benefit of adding additional patches. If patches are not independent with regard to environmental or genetic stochasticity, then adding additional patches is equivalent to simply adding the individuals they contain to an aggregate population size. That is, the meta-



population behaves as one unsubdivided population. This pattern is potentially very complex as the degree of correlation between patches may well vary from one type of environmental perturbation to another.

The one potential negative aspect of increasing patch number concerns contagious stochastic events. For example, consider forest fires as a form of contagious environmental stochasticity. The more patches there are, the more likely at least one will be affected by a forest fire during any particular time period (if patch number adds area). The larger the number of sites for initiation of a contagious disturbance, the more likely that any particular patch may be disturbed given that the degree of isolation does not change. How important a consideration this may be is, of course, unknown and is likely to be quite variable for species and from one habitat to another.

#### Patch Size

Because all forms of stochastic perturbations decrease in importance with increasing population size, increasing patch size should significantly reduce both site-specific and overall extinction probabilities. An important question is the form of the functional relationship between population size and  $e$ . Several theoretical models (MacArthur and Wilson 1967, Richter-Dyn and Goel 1972, Wright and Hubbell 1983) have demonstrated that, considering demographic stochasticity alone, the expected time to extinction in relation to population size for an isolated population takes the general form of an exponentially increasing function (fig. 2a). That is, starting from a population of one, the expected time to extinction increases so rapidly with an increase in population size (here expressed as  $K$ ) that, in the case of Richter-Dyn and Goel's model, by the time  $K=20$  (individuals) the population is essentially immortal with respect to any time period of potential interest to managers. This relationship is very sensitive to changes in  $r$ , the intrinsic rate of increase. Extreme caution should be used in interpreting the results of these models because they do not incorporate the effects of age-structure or environmental or genetic stochasticity. Shaffer and Samson (in press) show that incorporating age structure and environmental stochasticity drastically reduces the predicted population viability obtained from Richter-Dyn and Goel's model. More importantly, it must be remembered that the expectation of extinction even in a viable environment approaches one as time approaches infinity. Larger population size merely makes this approach more gradual (fig. 2b). Further, incorporating genetic stochasticity would likely have an equally significant effect, at least to some species. Thus, the whole class of models dealing with only demographic stochasticity becomes suspect for application to real world problems.

From a genetic standpoint, Franklin (1980) has argued that a minimum effective (in the genetic sense) population of at least 50 breeding adults is necessary to avoid the short-term deleterious consequences of inbreeding and that an effective population size of 500 may be necessary for long-term genetic adaptability. This argument suffers

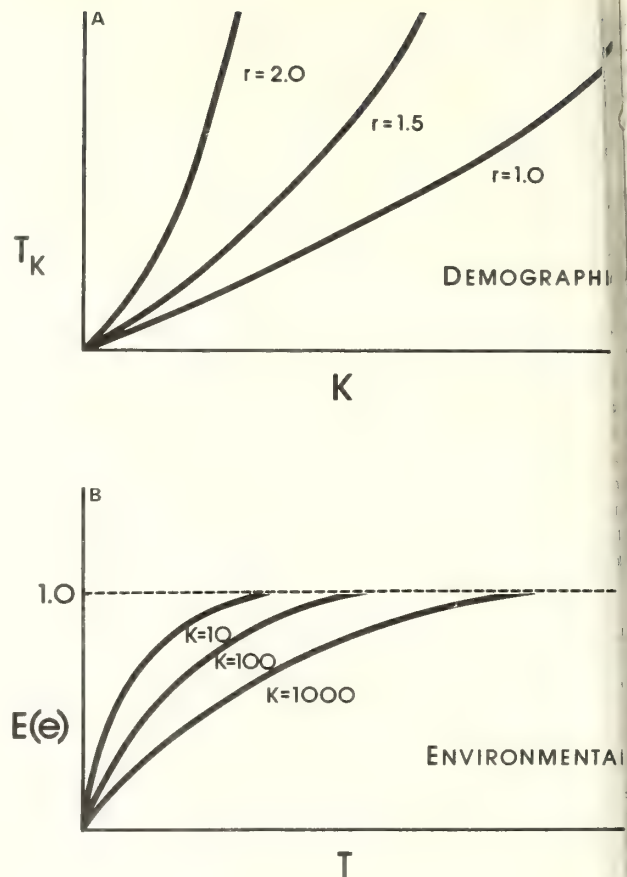


Figure 2: (A) The functional form of the expected time to extinction caused by demographic stochasticity for a population of size  $K$  ( $T_K$ ) as a function of population size ( $K$ ). This relationship is shown for three different intrinsic rates of increase ( $r$ ) (adopted from MacArthur and Wilson 1967).

(B) Hypothetical functional form of the expectation of extinction ( $E(e)$ ) caused by environmental stochasticity for a population size  $K$  as a function of time ( $T$ ). This relationship is shown for three different population sizes ( $K=10, 100, 1,000$ ).

many of the shortcomings found in the demographic models cited above. It does not include the effect of age-structure or environmental stochasticity. In fact, there do not seem to be any comprehensive theoretical models that integrate the various categories of stochastic perturbations. This is a crucial need for management and may prove an enlightening exercise for basic ecological theory.

Different species are likely to show different sensitivities to the various types of perturbations. For example, Karr (1982) presents evidence that, amongst forest birds in tropical undergrowth the variability in population size is a better predictor of extinction than population size itself. Karr interprets the coefficient of variation (CV) in population size as a first approximation of environmental variability. This result applies only to a subset of species sufficiently abundant to be considered immune to extinction from demographic stochasticity alone. This would seem to indicate that demographic stochasticity sets the lower limit on species survival but that environmental stochasticity is the most important factor above this lower limit.



rich (1983), based on his work with Bay checker-spot butterfly populations (*Euphydryas editha bayensis*), believes most local extinctions in this species are the result of catastrophic weather events and the effects on host food plants rather than "normal" variation in weather patterns.

Wills and Ballou (1983) present evidence that, for small populations of mammals, inbreeding depression has had a significant deleterious effect on demographic viability and suggest similar effects may occur in wild populations that become much reduced.

This is by no means a comprehensive review, but work with three different major taxonomic groups (birds, butterflies, mammals) has yielded three different indications of which type of stochastic perturbation may be most important in determining population viability. This area is rife with potential for theoretical, empirical, and experimental work.

#### Patch Isolation

The distance between patches is important because of its potential effects on the probability of interpatch movements and, thus, the operation of the rescue effect, the frequency of recolonizations, and the rate of immigration in maintaining a species' genetic variability, and the avoidance of inbreeding. Reduced isolation is a two-edged sword because, though it may produce the benefits mentioned above, it may also entail a high degree of interpatch correlation with regard to noncontagious environmental stochasticity and the facilitation of the spread of contagious environmental events. The relative importance of this mixed blessing is, of course, unknown and, again, likely variable.

Several efforts at modelling the importance of dispersal to population regulation and persistence (Roff 1974a, 1974b, 1975; Vance 1984) have produced some interesting results. Roff (1974a) demonstrates that, for populations with a stochastic exponential growth rate, increasing environmental stochasticity greatly reduces the probability of population persistence. If such a population is subdivided and there is movement of individuals between patches, persistence of this metapopulation configuration may be increased several orders of magnitude over the original undivided configuration.

Vance (1984), examining a number of population models, shows that, for a wide variety of dispersal patterns, dispersal tends to stabilize population fluctuations. In some circumstances, however, dispersal does not increase population stability. He further argues that the details of patch location do not alter the qualitative stabilizing effect of dispersal. At the scenario of his spatial argument (that is, equispaced patches all connected or all isolated) is too simplistic to be of interest for application.

The value of Roff's models, beyond their obviously important heuristic value, is limited by their consideration only of exponential growth. Vance's results are much more robust but suffer from an inadequate consideration of spatial effects.

Moreover, neither model incorporates the negative and potentially destabilizing aspects of dispersal, namely the effects of contagious stochastic events. As with the relationship of population size and extinction, assessing the effects of metapopulation configuration on persistence awaits the development of comprehensive, realistic models characterizing various life-history types.

#### The Trade-offs of Size, Number, and Distance

An examination of table 3 and the foregoing discussion summarize an intuitive expectation that many, large patches, which are close together, will usually minimize site-specific and overall extinction probabilities. Any conservation effort will necessarily be limited to some fixed amount of habitat and the question immediately arises of how best to distribute the habitat available.

If total habitat area is fixed then an increase in average patch size must correspond to a decrease in patch number. If the regional boundaries of the metapopulation are fixed then an increase in patch number may correspond to a decrease in patch isolation. If area and regional boundaries are fixed then an increase in patch size must correspond to a decrease in patch number and may entail an increase in isolation.

A small number of patches may be compensated for by large size and reduced isolation. Small patch size may be compensated for by increased patch number and decreased isolation. Increased isolation may be mitigated by increased patch number and increased patch size. Which strategy, or what mix of strategies, to use in any particular circumstance will depend on the particulars of that situation and the functional form of the relationships between the objective probabilities and metapopulation configuration variables. Without comprehensive models of the relationship of population size and configuration to extinction probabilities under the effects of all sources of stochastic perturbations, rational decisions on acceptable metapopulation configurations will not be possible. Even without such models, however, some preliminary guidance may be obtained from table 3. First, whether the objective is to minimize site-specific or overall extinction, increasing patch size should uniformly reduce the chances of extinction to all sources of stochastic perturbations. Neither patch number nor isolation is expected to have such an unambiguous effect on site-specific or overall extinction. This agrees with the results of Roff's (1974b) theoretical simulation models.

Second, additional patches should reduce both  $e_i$ 's and  $E$  but should have a more dramatic effect on the latter, contingent upon the degree of independence of the patches with regard to stochastic environmental perturbations. The hazards of increased patch number enhancing the probability of extinction caused by contagious stochastic events is unknown but probably minor.

Third, because isolation will often correlate inversely with the environmental independence of

patches but correlates directly with the ease of transmission of contagious stochastic events, lack of isolation is not an unambiguous blessing. A better knowledge of the prevalence and importance of the rescue effect and recolonizations relative to these potential disadvantages is necessary to better assess isolation's likely importance for minimizing site-specific and overall extinction. If the benefits of proximity outweigh the risks, then there is likely some tradeoff of distance with size, such that one configuration ( $A$ ) of a certain patch size ( $x$ ) and interpatch distance ( $y$ ) behaves (that is, has the same persistence/extinction schedules) as another configuration ( $A'$ ) of smaller patches ( $x'$ ) closer together ( $y'$ ) (fig. 3). Determining the existence and form of such a trade-off should be of great importance in maximizing management options for land-use planning.

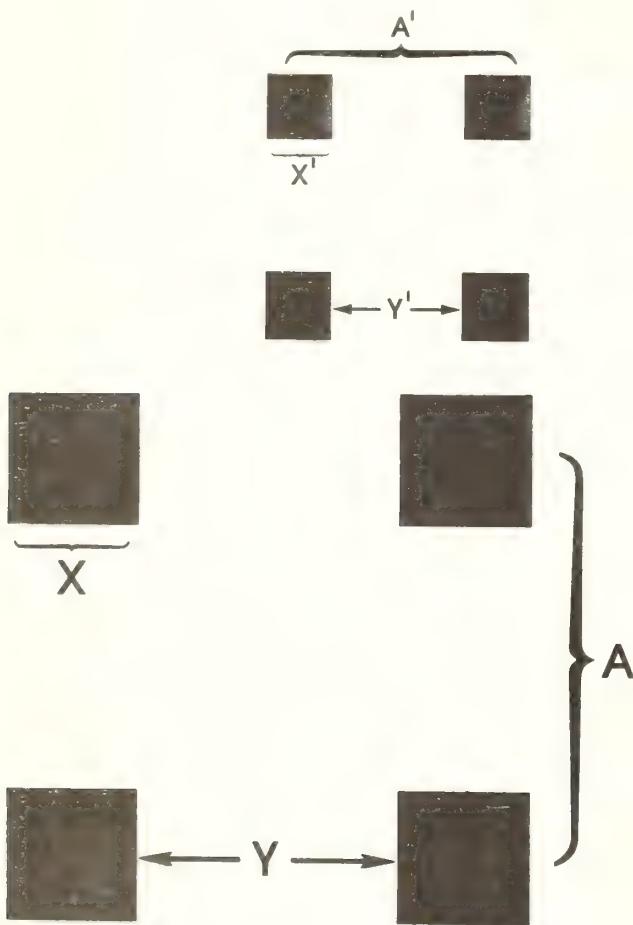


Figure 3.--The tradeoff of size and distance  $x' = \frac{x}{2}$ ;  $y' = \frac{y}{2}$  (not to scale). If there is a linear relationship of the effects of size and distance on extinction probabilities, site-specific and overall extinction probabilities should be equal in these two configurations.

What all of this means is that extinction/persistence probabilities are the result of the interplay of numerous forces, some opposing, that are determined, at least in part, by the configuration of the

habitat patchwork. Thus, there is likely no simple prescription for patchwork configuration that will universally maximize persistence or minimize extinction probabilities. It also means that the objective of metapopulation conservation must be explained because the effects of various alterations may have differing effects on differing extinction/persistence probabilities. In other words, what's best to reduce the overall extinction probability ( $E$ ) may not be best to reduce site-specific extinction probability ( $e_i$ ). For example, to minimize  $e$  for a given  $i$ , may require one very large patch, but minimizing  $E$  may require numerous, smaller patches of intermediate isolation.

A crucial corollary of the tradeoff of size and distance, involves the twin dangers of metapopulation restriction and diffusion (fig. 4). In most scenarios conservationists will have to accept less than all of the remaining habitat for a species of concern. One goal of conservation is to maintain the representative distribution of a species. Yet specialized management can be administratively burdensome. The dilemma may then be one of choosing a dispersion pattern either to maximize the species' geographical representation or to minimize the administrative burden. These may be opposing goals. Minimizing administrative burdens may require dedicating a number of patches close together and not having to deal with the species elsewhere. Geographic representation may require that patches be widely dispersed. The closer patches are, the more likely they are to behave as one. Thus, the potential to lose the species increases due to a contagious stochastic event or the fact patches are so close (for example all in one watershed) that they are essentially one with regard to environmental perturbations. This is the danger of restriction. On the other hand, maximizing dispersion may lead to a patchwork whose interpatch distances are so great that each patch behaves as an isolate (that is, dispersing individuals cannot reach another patch), and there is no realized benefit in terms of the rescue effect, recolonization, or gene flow. This is the danger of diffusion.

Clearly, this "stew" of processes, variables, and probabilities would be rendered more meaningful, if:

1. Data were available to derive the functional relationship of the objective probabilities to the various processes as these change with the various metapopulation configuration variables.
2. Theoretical models integrating the four types of stochastic events were available for both a single population and a metapopulation configuration for a variety of life-history types.

It would seem that realistic, theoretical models, be they analytical or numerical, could aid in determining the sensitivity of metapopulation persistence to various changes in metapopulation configurations. In table 3 I've indicated a postulated qualitative effect with a directional arrow. A next level of understanding would be to know which arrows are large and which small. Theoretical models may provide this. Eventually arrows could



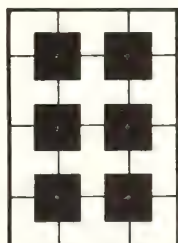
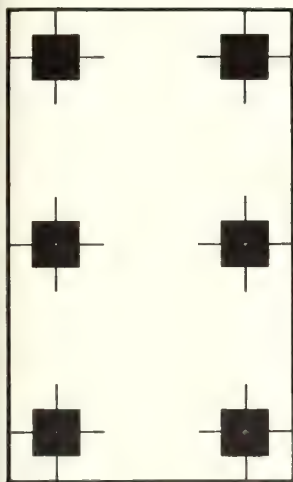
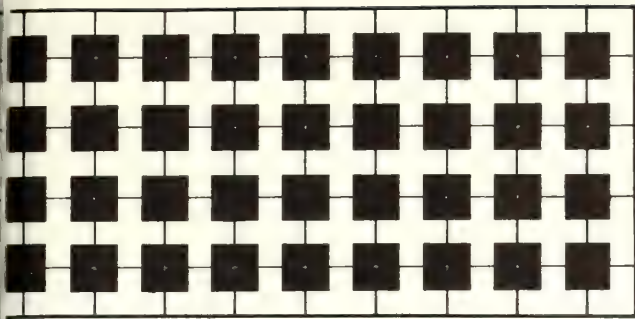


Figure 4.—The dangers of restriction and diffusion. 4A represents an original, unaltered metapopulation, most of which is scheduled for alteration. Management must be careful not to spread patches so thin that patch interactions are lost and each patch goes extinct relatively rapidly (4B), nor leave so few patches so close together that, despite patch interaction, all patches are eliminated by one catastrophic event (4C).

replaced with equations but this will require extensive empirical and experimental work.

#### THE SPECIAL CASE OF THE NORTHERN SPOTTED OWL

How does the foregoing discussion relate to the current problem of conserving the northern spotted owl in public forest lands in the Pacific Northwest? From the reports on current research and management programs, much important data are being gathered on this species, particularly with regard to dispersal and the survivorship of young. In addition, research to date (Forsman and others 1984, Stierrez and others 1983) has shown the species' preference for mature and old-growth timber for foraging, roosting, and nesting; revealed a large home range size; demonstrated the variable success of the species' reproductive performance; and provided some estimate of overall population size and distribution. All this information is necessary, but it is not yet sufficient for comprehensive conservation planning. Still lacking are sex- and age-specific mortality and fecundity rates; sex and age structure (which may be derived from the receding); some measure of the variability of

these rates from year to year, and data on the genetic and breeding structure of the species. Thus, there are insufficient data with which to construct a comprehensive quantitative population model.

In the absence of sufficient data to develop comprehensive quantitative approaches to assessing the viability of various spotted owl habitat configurations, two management approaches have emerged. The first is what might be termed a qualitative approach; using available information on population size, distribution, habitat preference, home range size, and an intuitive appreciation of the importance of dispersal, to develop guidelines for management (Oregon Interagency Spotted Owl Management Plan). The other approach incorporates the above but is based on the growing use of genetic arguments to assess minimum viable population sizes (Salwasser and others in press). With regard to the former approach, its chief weaknesses are the need for a better understanding of how home range size and the relative composition of mature and old-growth (that is percent composition - a rough measure of habitat quality) impinges on reproductive success, adult survivorship, and their variability; and the apparently arbitrary choice of distances between spotted owl management areas (SOMAs). Current work on dispersal should help correct the latter weakness fairly quickly, while extensive studies of reproductive success across a gradient of home range size and percent composition can partially alleviate the first weakness. For the temporal component of variation in SOMA suitability by size and percent composition there is simply no substitute for long-term monitoring. Certainly, using minimum-sized home ranges for long-term management guidelines would be courting failure as would a spacing regime for SOMAs based on maximum dispersal abilities. Combining these hazards with a dedication of a minimum number of SOMAs of low quality would further reduce the species survival probabilities.

The genetic approach represents a conceptual advancement based on both theoretical and empirical knowledge. However, several cautionary notes need to be sounded. First the 50/500 rule (Franklin 1980, Soulé 1980) discussed earlier, which seems to be emerging as a standard of application, is based on the simplest of analytical population genetics models, which do not take into account either age-structure or environmental stochasticity. Based on previous work on modelling grizzly bear (*Ursus arctos*) populations, the inclusion of age structure can dramatically affect the results of projecting population survivorship based on demographic stochasticity alone (Shaffer 1978). To the extent that genetic diversity directly affects demographic parameters (for example, mortality, fecundity), and this is the heart of the inbreeding depression argument, the inclusion of age-structure in determining effective population sizes may dramatically increase estimates of minimum viable population sizes. Make no mistake, there is no doubt that inbreeding depression poses a grave risk to small, isolated populations. What remains in doubt is what constitutes small for organisms of varying genetic structure and life-history patterns.



In this regard, Barrowclough and Coats (1985) estimate that the likely effective population size (in the genetic sense) for this species would approximate 2.1 of the census population size. This means that to achieve the goal of long-term adaptability (500 breeding adults, Franklin 1980) may require a census population goal of 1050 breeding adults or 525 pairs. This is very close to the current management objective of 500 pairs for Washington and Oregon (Salwasser and others in press).

A second point reiterates what emerged from the preceding consideration of metapopulation extinction dynamics. There currently exists no integrated theoretical model providing guidance on which class of stochastic events sets the lower limit to population viability. Implicit in the assumption of the 50/500 rule is that, if these sizes are sufficient to overcome the dangers of drift and inbreeding depression, all is well. This remains to be demonstrated. In fact, for density independent populations occupying variable environments, environmental stochasticity may be the limiting factor for population persistence, as appears to be the case in certain checkerspot butterfly populations (Ehrlich and others 1980). On the other hand, for large-bodied, long-lived, adaptable species with low genetic variability and some tolerance to inbreeding, demographic stochasticity may be the key factor in determining population persistence. How much demographic considerations or environmental conditions would modify the current management objective for the northern spotted owl is unknown, but it is highly probable an increase in the objective would be required.

#### MANAGEMENT OPTIONS AND RESEARCH NEEDS

It is clear from the discussion in the section, "Metapopulation Configuration and Stochastic Extinction Dynamics," that projecting the survivability of various metapopulation configurations is a daunting task. It is safe to say there are insufficient time and resources available to determine, empirically, all the requisite data over a sufficient period to ensure developing an accurate predictive capability for projecting population persistence of the spotted owl. This is a general and fundamental problem in conservation biology today; being asked to determine the long-term viability of wildlife species based on short-term studies. Nevertheless, the issue must be addressed. A reasonable strategy involves three components: (1) theoretical research, (2) short-term empirical studies and (3) integration of a long-term monitoring-research program with current management action (Salwasser and others in press).

#### Theoretical Research

As discussed above, theoretical ecology lacks the detailed models necessary to provide sound guidance on the interplay of the factors affecting stochastic extinctions for populations of different life history patterns. It seems reasonable that the management agencies in need of such guidance should seriously consider instituting a program of basic research to address this weakness. In my judgment

a few representative simulation models of various major life history types would go a long way toward providing at least sound qualitative guidance on the likely persistence of various populations in relation to various stochastic factors and various land-use patterns. Such generalized models would also be useful in generating hypotheses for empirical field or experimental laboratory studies. There can only be a growing need for such guidance in the future. We may as well start now. In this regard it is very encouraging to learn of efforts by the USDA Forest Service to develop an interactive computer simulation model of vertebrate population dynamics that incorporates demographic, environmental and genetic stochasticity (Salwasser pers. comm.).<sup>1</sup> Such a modelling effort can be expected to make a major contribution in wringing the most value from the data at hand and helping to pinpoint the most crucial data gaps. Expansion of this model from a single isolated population format to a metapopulation configuration should provide a truly useful tool, not only for management but for theoretical studies as well.

#### Short-Term Empirical Studies

For the northern spotted owl, short-term empirical studies should focus on assessing reproductive variability across a gradient of home-range size by percent composition; some measure of the genetic variability of the species; further work to determine dispersal behavior and success; and monitoring of suitable habitat, occupied and vacant, to assess the relative frequency of pair extinction and the recolonization of patches. Work on the latter item is underway (Carey 1985). Efforts should also be made to determine why this species prefers old growth. There is some suggestion that prey availability may be the greatest in old growth but that prey are abundant yet unavailable, in early successional stages (Gutiérrez and others 1985). If this proves true silvicultural options may be available to enhance the species' use of a wider variety of habitats.

#### Long-Term Monitoring of Management Actions and a Research Program

To the extent that agencies must act now to determine the species' habitat needs, the following guidelines may serve as a reasonable approach provided they are linked to the long-term monitoring research program specified.

Patch Number. The goal of 500 breeding pairs (Oregon Interagency Spotted Owl Management Plan), in the absence of better guidance, should be increased to 1,000 pairs for the subspecies. This goal of 1,000 pairs would apply to Washington, Oregon and northern California. While this number may seem large, it represents a 60 percent reduction from the most recent range-wide estimate of the subspecies' abundance (U.S. Fish and Wildlife Service 1982). Moreover, given our current

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understanding of the species genetic characteristics (Rowlough and Coats 1985) this increase represents roughly a doubling of what would be necessary to meet the admittedly rough minimal requirements for long-term adaptability (Franklin 1980) currently employed by the USDA Forest Service. In addition, it should be noted that the emerging patchwork will result in localized populations a size that will be extremely vulnerable to demographic stochasticity. Thus  $e_i$ 's can be expected to be high. The low rates of survivorship and reestablishment of juveniles during dispersal (Allen and Brewer 1985, Gutiérrez and others 1985, Meslow and Meslow 1985) indicate a low  $m$  value can be anticipated. Recall that, for the species to persist  $m$  must be greater than  $\bar{e}$ . Adding SOMAs could help assure this condition is met.

Further, if a management program is based on 1,000 sites and no suitable unoccupied sites are reserved, it is unlikely that 1,000 sites will always be occupied (Salwasser and others in press). Thus the effort should be made to determine the current percentage of occupancy of suitable habitat and then use this percentage to correct for the number of patches necessary to actually maintain 1,000 sites. All of these considerations point to a need to increase the SOMA objective for the species, at least until better information is available.

Patch size.--In the absence of better guidance, SOMA size should be based on mean size and percent composition of those areas sampled so far where the species has successfully bred. This could be substituted based on further sampling and the results of the reproductive variability studies.

Distribution.--SOMAs should be located no more than the median (Miller and Meslow 1985) distance of documented successful dispersals. This is conservative but until more data are available it's probably the prudent course to follow. Corridors of mature or old-growth forest, particularly riparian corridors, might aid inter-SOMA dispersal. It is of concern that, to date, radiotelemetry studies in Oregon and northern California have shown very low survivorship rates for dispersing juveniles (Allen and Brewer 1985, Gutiérrez and others 1985, Miller and Meslow 1985). This inevitably raises the question of whether habitat fragmentation has already produced a metapopulation configuration where  $m < \bar{e}$ . These findings highlight the need for more work on dispersal and adult survivorship, and patch extinction and colonization rates.

A long-term monitoring research program should focus on estimating adult survivorship; further monitoring pair extinction and colonization rates; and reproductive success across a gradient of SOMA size/percent composition over time. Work should also be instituted to determine what habitat manipulation techniques may be effective and feasible to actively manage the species if it appears the network of reserved areas is failing. It is encouraging that the Pacific Southwest and Pacific Northwest Regions of the USDA Forest Service are actively pursuing the latter recommendation (Salwasser, pers. comm.).<sup>2/</sup>

## SUMMARY

The importance of island biogeographic theory to conservation is the attention it has focused on the importance of understanding localized extinctions and colonizations, and the factors affecting these processes, as determinants of the distribution and persistence of species. This focus has triggered an increased appreciation of the role of chance in determining the patterns manifest in nature. The indications that such simple variables as habitat size and isolation may play key roles in determining population persistence in the face of chance events is of crucial importance in an increasingly fragmented world where the land-use patterns imposed by man are often inimical to the survival of certain species. Nowhere is this more evident than in considering the fate of a species whose patchwork of habitat is undergoing alteration. If persistence hinges on the number, size, and interrelationship of patches, at what point will the fabric of habitat be stretched too thin and the species lost? The northern spotted owl in the Pacific Northwest is one current problem that fits this scenario. A new paradigm, or perspective, on population structure and dynamics is essential to deal effectively with the conservation of such species. The metapopulation concept seems an appropriate frame of reference for this class of problem, yet ecological theory has yet to provide a realistic model to assess even the qualitative behavior of such a population configuration under the influence of all the various types of stochastic perturbations that are likely to affect populations. Even without such models, common sense would indicate that a large number of large patches close together should minimize the loss of species both from particular patches and over all patches. Yet further reasoning from common sense indicates that there may be more subtle effects and these may produce tradeoffs in habitat configurations which, though spatially different, confer the same probability of persistence to the species in question. Determining the existence and form of such tradeoffs is crucial to maximizing management alternatives to "fit nature in."

In the case of the northern spotted owl, valuable data have been gathered but the effectiveness of this information is constrained by the lack of theoretical models to provide qualitative guidance about which data are most important. The current USDA Forest Service approach to the management of this species (Salwasser and others, in press) is encouraging but will benefit by expanding its focus on genetic arguments to include the effects of demographic and environmental effects. The northern spotted owl highlights the whole issue of land-use planning for the conservation of viable populations. This issue is complicated by the lack of a scientific consensus on standards for what constitutes such a population and by the inescapable reality that we are being asked to project

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the dynamics of a system without being given the time to examine it empirically or experimentally. I see no solution to this except that pointed out by Salwasser and others (in press): to stimulate theory to provide guidance and generate hypotheses that may be tested in the context of the management programs which will be implemented without complete knowledge. I hope management will be allowed to adapt in the future in the light of the experience thus gained.

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## A SUMMARY OF THE SCIENTIFIC BASIS FOR SPOTTED OWL MANAGEMENT

Andrew B. Carey

**ABSTRACT:** This paper is based on the presented papers and discussions at the symposium "Ecology and Management of the Spotted Owl in the Pacific Northwest: Conflicts and Opportunities" held in Arcata, California, in 1984. Additional information is drawn from published scientific reports and unpublished administrative study reports. The information is synthesized into a summary of the basis for managing spotted owls. Management for spotted owls has generated controversy because of conflicts with timber production and because there was little information on the ecology of the owl prior to the 1970's. Substantial information on the spotted owl has now been accumulated although much of this information has not been published. The accumulated information shows that spotted owls need old-growth forest to maintain healthy populations. Between 2,000 and 2,500 acres of old growth are used, on the average, by a pair of spotted owls. Existing information suggests that at least 1,000 pairs of northern spotted owls are necessary to maintain a viable population. This will require maintaining more than 1,000 spotted owl management areas because not all SOMAs will be occupied. Existing guidelines for distributing spotted owl management areas seem adequate. Major informational needs include an inventory of old growth, an assessment of how well present management is accomplishing goals for spotted owls, quantitative data on spotted owl demography, and a greater understanding of what constitutes a viable population. Monitoring the results of spotted owl management will be essential to ensure that population goals are met.

### INTRODUCTION

A major problem for the resource management agencies in the Pacific Northwest is ensuring

that there is sufficient information for managers about the spotted owl (*Strix occidentalis*). During the 1970's management for spotted owls achieved regional prominence among wildlife issues because of the owl's apparent dependence on old-growth coniferous forests that also have high value as timber. The spotted owl was described as declining in numbers because of harvesting of timber and was accorded special status by California, Oregon, and Washington (Carleson and Haight 1985, Forsman and others 1982, Gould 1985, Heinrichs 1983, Juelson 1985). Because of its special status, its role as a surrogate for other wildlife associated with old-

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growth forests, and its prominence in the public arena, the owl was designated a management indicator species by the USDA Forest Service (Carrier 1985, Lee 1985). During the 1980's the spotted owl achieved national prominence because of the conflict between harvesting timber and ensuring that spotted owl populations remain viable as required by the National Forest Management Act (Forsman and others 1982, Heinrichs 1983, Meslow and others 1981). The controversy over the spotted owl was exacerbated by the lack of information available in the 1970's on spotted owl habitat requirements (Heinrichs 1983). Prior to 1977, the only published information was either very general in nature or anecdotal and dealt with individual observations of the bird and its habitat, nests, and food habits. The first quantitative study appeared in a scientific journal in 1977 (Forsman and others 1977). The results of many studies are still in unpublished reports, manuscripts in preparation, or manuscripts in press (Campbell and others, in press). Reviews of the owl's ecology that were used to prepare management recommendations (for example, Zarn 1974, Department of the Interior 1982) had to be based on theses, anecdotes, unpublished reports, and personal communications. Even now there is only one major, published, scientific treatment of the spotted owl in the Pacific Northwest (Forsman and others 1984) and only a few research reports in journals that require rigorous technical review before publication (Barrows 1981, Forsman and others 1977, Marshall 1942, for example). The symposium Ecology and Management of the Spotted Owl in the Pacific Northwest: Conflicts and Opportunities was convened in 1984 (Gutiérrez and Carey 1985) to bring together the rapidly accumulating information on the spotted owl. This paper summarizes the papers in that symposium and other published and unpublished information to analyze the sufficiency of information available to managers.

#### What Constitutes Sufficient Information?

To determine what constitutes sufficient information for management purposes, six things must be considered: (1) The objectives of the managing agency. (2) The present management situation and the options available to the agency. (3) The accumulated information. (4) Forthcoming information. (5) The state of wildlife science in terms of the development of theory and reliable predictive models. (6) Research needed and the costs, difficulty, methods, and likelihood of obtaining additional useful information in the near future. Each of these is discussed. Much of this analysis is directed towards the Pacific Northwest Region of the USDA Forest Service because it contains a majority of the remaining habitat for northern spotted owl (*S. o. caurina*) habitat. Habitat is also being managed by the Pacific Southwest Region of the Forest Service, and by the National Park Service, and Bureau of Land Management in the U.S. Department of the Interior.

#### OBJECTIVES OF THE MANAGING AGENCIES

Of all the laws relating to Forest Service activities (U.S. Department of Agriculture 1983), the National Forest Management Act of 1976 provides the clearest, most comprehensive direction both for overall policy and objectives and for managing forests for wildlife. The regulations implementing the act (MacCleery 1982) provide even more specific guidance: the dominant principle of Forest Service planning and management is to "provide for multiple use and sustained yield of goods and services from the National Forest System in a way that maximizes long-term net public benefits in an environmentally sound manner." This balance between producing goods and services and protecting the environment is maintained throughout the act and the regulations and is exemplified in specific, minimum requirements for management. These requirements include maintaining the diversity of plant and animal communities to meet multiple-use objectives and providing habitat adequate to maintain viable populations of existing native vertebrate species.

Both the Pacific Southwest Region and the Pacific Northwest Region of the Forest Service recognize that the spotted owl has special habitat needs and that changes in its population may reflect the effects of management activities. Both regions have adopted plans to maintain viable populations of spotted owls (Carrier 1985, Lee 1985). And both have recognized the value of old-growth coniferous forests as habitat for the spotted owl and other wildlife and as an integral component of natural diversity (Franklin and Spies 1984, Kerrick and others 1984, Salwasser 1984, Sirmon 1984, Teeguarden 1984). Simply stated, the Forest Service objective for spotted owls is to provide an environment that will maintain viable populations of spotted owls throughout their existing range across the National Forests. But the situation facing managers is not simple.

Because the spotted owl depends on mature and old-growth forests, maintaining an environment that is amenable to spotted owls will affect the level of sustained yield of wood products. Viable populations of spotted owls probably would be maintained if mature and old-growth forests were not harvested. But long-term net public benefits might not be maximized. Although the National Forest Management Act of 1976 emphasizes production of goods and services, it also states that multiple use is "not necessarily the combination of uses that will give the greatest dollar return or the greatest unit output." Viable populations of spotted owls must be maintained within a management arena that dictates minimum impact on the harvest and production of timber. Additional information on spotted owls is required primarily because of the need to balance spotted owl populations and wood products.

What kind of information do managers need to achieve this balance? To a major extent, the need for information is conditioned by the options that are available. If, in the current management situation, there is a great surplus of owls and owl habitat, managers will have many choices. If the spotted owls and their habitat are already



near minimum levels, few choices are left. If suitable habitats can be created in a short time, more options are available than if a long time is required or if habitat cannot be recreated.

If the management situation is favorable (many options exist), then precise and accurate descriptions of the requirements of spotted owls could be used to select habitat management areas. But if few options exist, then the information that is more qualitative than quantitative would be sufficient because few choices could be made. The situation is complicated further by the lack of a clear understanding of what constitutes a viable population. Information on the spotted owls must be placed in a theoretical framework that defines "viable population." The theory is relatively undeveloped as is the concept of dependency of a species on particular types and amounts of habitat (Barrowclough and Coats 1985; Carey 1984; Shaffer 1981, 1985).

#### THE PRESENT MANAGEMENT SITUATION AND OPTIONS AVAILABLE

##### Old Growth and Spotted Owls

Of the 15 million acres of old-growth (250-750 years old) forest (forests 250 to 750 years old) present in the Pacific Northwest in the 1800's, about 5 million acres remain. About 1 million acres are reserved in national parks, wilderness areas, and research natural areas in western Washington and Oregon (Franklin and Spies 1984). About 25 percent of the National Forests in the Pacific Northwest west of the crest of the Cascade Range consist of forests more than 250 years old and amount to 2-1/2 million acres (Sirmon 1984). Some of the old growth is subalpine forest not suitable for spotted owls. The distribution of old-growth (and mature) forest is not even. Old growth is concentrated in the national parks and in the National Forests along the west slope of the Cascade Range. Old growth is not abundant in the valleys and mountains west of the Cascade Range except in parts of Olympic National Park. The State of Washington, Department of Game, feels that the remaining habitat on the Olympic Peninsula is insufficient to support a viable population of spotted owls (Juelson 1985). Certainly the amount of old growth remaining in the Olympic National Forest is insufficient (Beckstead 1985). The State of Oregon, Department of Fish and Wildlife, is concerned about the population in the Oregon Coast Range because of the relatively small amounts of old growth that remain and because plans are to remove much of the remaining old growth (Carleson and Haight 1985). The present populations of spotted owls are about 1,200 pairs in Oregon (Carleson and Haight 1985), 1,000 pairs in Washington (U. S. Department of the Interior 1982), and 1,260 pairs (of two subspecies) in California (Gould 1985). These populations will probably decrease with continued harvesting of mature and old-growth timber (Forsman and others 1982).

#### The Spotted Owl Management Plan

Present management of spotted owls in National Forests in Oregon and Washington is based on the "Spotted Owl Management Plan" (unpublished) prepared by the Oregon-Washington Interagency Wildlife Committee. The committee based its recommendations on the preliminary results of research conducted by Eric Forsman of Oregon State University; the plan and the events relating to the formulation of the plan are summarized by Forsman and others (1982). Forsman's research has been published (Forsman and others 1984, Forsman and Meslow 1985). The final recommendations of the committee were adopted by the Pacific Northwest Region (Lee 1985) and the Pacific Southwest Region (Carrier 1985) of the Forest Service but not by the Oregon State Office of the Bureau of Land Management (Carleson and Haight 1985). Initially both Federal and State agencies were reluctant to adopt the committee's recommendation because of the lack of information on spotted owls. The state forestry agencies of California, Oregon, and Washington still have not accepted the recommendations. Even so, there is concern about whether or not the Federal agencies are doing enough (or conversely, doing too much at the expense of other resources) for the spotted owl (Carleson and Haight 1985, Gould 1985, Heinrichs 1983, Juelson 1985, La Follette 1979, Lee 1985).

Current management plans of Federal agencies (Forest Service, National Park Service, and Bureau of Land Management) would preserve the habitat of 800 to 1,000 pairs of northern spotted owls in the Pacific Northwest. The Forest Service has set goals of maintaining 530 pairs of spotted owls in Washington and Oregon (Lee 1985) and 500 pairs (of all subspecies) in California (Carrier 1985).

##### Options

What options are there for managers? The Pacific Northwest Region considered 530 pairs for its minimum goal and 690 pairs as an alternative high goal. Thus the managers in the Region had a fair range of options available. But the Region is reassessing the range of options, and the associated risks, through preparation of a supplemental environmental impact statement on the regional guide for forest plans. Individual National Forests in the Pacific Southwest Region are also considering alternative goals. The options available to the Bureau of Land Management are not clear. The National Park Service is charged with maintaining a natural environment, a charge that is compatible with maintaining spotted owl populations.

A full exploration of the options available to the Federal management agencies has not been possible because there is no inventory that contains the locations, sizes, and characteristics of the mature and older stands not scheduled for harvest. It is not possible without such an inventory for researchers to determine the present distribution of stands and the possible arrays that could form alternative networks for maintaining spotted owls. It also is not possible to select stands of specific structural characteris-

tics, sizes, and distributions to ensure that if a minimum number of owls are maintained, they will be maintained in the highest quality environment.

## THE ACCUMULATED INFORMATION

### Spotted Owl Distribution

Bent (1938) reported that the spotted owl inhabited a variety of forested environments in western North America ranging from dense, coniferous forests in British Columbia to pine-oak woodlands in Mexico. However no sightings of spotted owls have been reported in British Columbia in recent years (Howie 1980). Until 1970, the spotted owl was thought not to commonly occur in the Pacific Northwest; only 24 sightings of spotted owls in Oregon had been recorded (Forsman and others 1982). Since 1972 numerous surveys for spotted owls have been conducted by biologists employed by Federal and State agencies, industry, and private organizations. Some results have been published (Erckman 1982; Forsman and others 1977, 1982, 1984; Garcia 1979; Gould 1977; Marcot and Gardetto 1980; Postovit 1979); others have not (many are listed by Campbell and others in press); and some surveys are ongoing (for example, Allen and Brewer 1985). Forsman and others (1982) tabulated many of the 1972-81 surveys: spotted owls had been located at over 400 sites in California, 500 sites in Oregon, and 200 sites in Washington. The population size for the northern spotted owl (*S. o. caurina*, the subspecies in the Pacific Northwest) was estimated to be roughly 2,500 pairs (U. S. Department of the Interior 1982).

### Spotted Owl Habitat

Survey results.--Although many of the sites surveyed by biologists have not been described using standard, quantitative measures, the records show the most spotted owls were found in late seral forests; this substantiates the observations of naturalists during the early 20th century that the spotted owl was associated with old, virgin forest.

Forsman and others (1984) describe 595 sites in Oregon that were occupied by spotted owls, perhaps 50 percent of the occupied sites in Oregon. Most (98 percent) of the sites were old-growth (more than 200 years old) coniferous forests or virgin forests that were mixtures of mature stands (100 to 200 years old) and old-growth stands. The salient features of the occupied sites were: an overstory composed of trees 230 to 600 years old; an understory of trees 30 to 200 years old, canopy closure averaging 65 to 80 percent as a result of the uneven-aged, multilayered structure; and the presence of broken tops, deformed limbs, and heart rot in large trees. Of 47 nests located, 90 percent were in the classic old growth just described; the remainder were in younger forests that contained scattered old-growth trees. Nest trees averaged 49 inches in d.b.h. (diameter at breast height) and none were less than 29 inches in d.b.h. Nests were 39 to 180 feet above the ground averaging 75 feet in cavities or broken tops of trees or on platforms of sticks and debris on tree limbs.

Other, less extensive surveys gave the same results as Forsman's. Cordano and Cordano,<sup>1/</sup> surveyed dense stands of mature to old-growth timber near streams in northern California. They found owls in 80 percent of the stands. Marcot and Gardetto (1980) surveyed a variety of stands in northern California: 95 percent of the owls they encountered were in mature or old-growth stands, which occupied only one-third of the area surveyed. Spotted owls were three times more abundant in old-growth forests than in mature forest. Gould (1977) describes 192 sites where he found spotted owls in northern California. The owls were found in dense, virgin, coniferous forests between 98 feet and 7,500 feet elevation. The sites contained mature forests with trees greater than 33 inches d.b.h., a variety of tree species, a multilayered canopy, canopy closure greater than 40 percent, and a moderate degree of decadence. In Oregon, Forsman and others (1977) surveyed areas in the Cascade and Coast Ranges, including extensive areas of second-growth forests 40-90 years old. Owls were 12 times more abundant in old growth than in forests that were less than 80 years old. Postovit (1979) surveyed extensive areas, including unbroken second growth, in the Cascade Range and the Olympic Mountains of northwestern Washington. Spotted owls were five times more abundant in old-growth forests than in younger forests. Only one owl was found in unbroken second growth. Abundance rapidly declined with declining proportions of old growth. Garcia (1979) surveyed stands of various ages in the Gifford Pinchot National Forest in southwestern Washington. He found owls in stands ranging in age from 60 to over 200 years old, but his data were too few for comparing age classes. Erckman (1982) found spotted owls to be widely distributed in old-growth forests in the Mount Baker-Snoqualmie National Forest in northwestern Washington. He concluded that all old growth was not of equal value to spotted owls. Areas below 3,200 feet in elevation and containing major creek drainages had higher owl densities than higher, drier sites. Forsman and others (1984) and Gould (1977) also found altitudinal limits and commented on the need for water.

Radio telemetry results.--Radio telemetry studies of adult spotted owls in mosaics of old-growth, mature, and young stands in western Oregon (Forsman and others 1984) and northern California (Gutiérrez and others 1984) confirmed the association of spotted owls with mature and old-growth stands. Ongoing studies in Washington are obtaining similar results (Allen and Brewer 1985).

In Oregon, home ranges of individual spotted owls encompassed 1,356 to 8,349 acres, averaging 2,907 acres in the Cascades where 55 percent of the area studied was in old growth and 4,725 acres in the

<sup>1/</sup>Unpublished administrative study report, 1981, "A Preliminary Study of the Spotted Owl on the Corning Ranger District," by Anette Cordano and Marty Cordano, U. S. Department of Agriculture, Forest Service, Mendocino National Forest, 420 E. Laurel Street, Willows, CA 95988.



Coast Range where 20 percent of the area studied was in old growth. The amount of old growth encompassed in the home ranges was 741 to 2,878 acres, averaging 1,988 acres in the Cascades and 1,245 acres in the Coast Range. None of the six pairs of spotted owls studied had less than 1,008 acres of old growth in its range (Forsman and others 1984, Forsman and Meslow 1985). The average amount of old growth in a pair's range was 2,264 acres (Forsman and Meslow 1985). These figures and all the figures for owls in the Coast Range are based on only 4 months of study during summer. In the Cascade Range, owls were studied from 9 to 13 months; the data indicated that 4 months of study are insufficient to adequately determine total home range use. The owls used old growth for foraging 64 to 99 percent of the time despite the low proportions of their ranges in old growth (20 to 66 percent). Owls spent 0 to 16 percent of their time foraging in mature stands and 0 to 36 percent in young (61 to 80 year old) stands. The owls also foraged in 25- to 35-year-old forests in the Coast Range (0 to 31 percent of the time) but not preferentially (up to 47 percent of the home ranges were 25- to 35-year-old forests). The only preference (use out of proportion to occurrence) demonstrated was for old growth. More than 1,600 roosts were located; 91-98 percent were in old-growth forest; 90 percent of the nests located were in old-growth forest.

Preliminary results of two northern California studies were reported by Gutiérrez and others (1984). Home range sizes for six owls were 741 to 3,705 acres or an average 2,245 acres. Home ranges of adult pairs exceeded 3,000 acres and contained more than 2,000 acres of mature and old-growth forests. Mature and old-growth forests comprised 22 to 52 percent of summer home ranges and 11 to 66 percent of winter home ranges. Mature forests in the California study area were more than 150 years old and had multilayered canopies; dominant trees were larger than 39 inches d.b.h.<sup>2/3/</sup> Late seral stage forests were used out of proportion to their occurrence. Data analysis is incomplete, but results to date agree with the results reported by Forsman and others (1984) (Gutiérrez and others 1984). In both studies home range size increased as the proportion of old growth decreased, further substantiating the need for some minimum area of mature and old-growth forest.

A correlation was also found in radio telemetry studies in Washington between home range size and the amount of old growth contained in the home range. Three adult pairs had an average of 1,850 acres of old growth in their home ranges (Allen and Brewer 1985).

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<sup>2/</sup>Personal communication, R. J. Gutiérrez, Humboldt State University, Arcata, CA 95521.

<sup>3/</sup>Unpublished administrative study report, "Winter Ecology of Radio-Tagged Owls on Six Rivers National Forest, Humboldt County, CA," by Chuck Sisco, Humboldt State University, Arcata, CA 95521.

Laymon (1985) is conducting radiotelemetry studies on California spotted owls (S. o. occidentalis) in the Sierra Nevada. He has observed a marked altitudinal shift in home range from summer to winter. The four owls he monitored moved 12 to 20 miles to areas that were an average of 2,296 feet lower in elevation than were the summer home ranges. These owls returned to the summer home ranges in the spring. Seasonal adjustments in home range have been noted by all the biologists studying the northern spotted owl but none of these adjustments approached the migratory nature of the California spotted owl observed by Laymon. Laymon's research underscores the importance of studying a species throughout its range.

Radio telemetry studies have shown that dispersing juvenile spotted owls will frequent young forests and even clearcuttings. But mortality rates of juveniles are very high. Juveniles have the capability to disperse long distances before dying (up to 61 miles, but averaging 15 to 28 miles, depending on the area). There is no such information on successful dispersers (owls that disperse, establish a territory, mate, and produce offspring). The juveniles do not cross large bodies of water (for example, reservoirs or Hood Canal). They will cross rivers 246 to 328 feet wide. They often disperse along forested corridors, such as riparian areas, and they will cross ridges. Studies of dispersing juveniles are being conducted in California, Oregon, and Washington (Allen and Brewer 1985, Gutiérrez and others 1985, Laymon 1985, Miller and Meslow 1985).

A test of a habitat model.--Laymon<sup>4/</sup> developed a Habitat Suitability Index model for spotted owls based on Forsman's research with some consideration of other studies. The model includes tree size, canopy closure, vertical layers of vegetation, and area. The model was tested on the Eldorado National Forest in California. The test confirmed the association of spotted owls with large trees (greater than 30 inches d.b.h.), high canopy closure (70 to 100 percent), and multilayered understory.

Summary of spotted owl habitat.--Spotted owls in the Pacific Northwest use all the major coniferous forest associations except subalpine forests and forests of ponderosa pine (Pinus ponderosa Dougl. ex Laws), lodgepole pine (P. contorta Dougl. ex Loud.), or sitka spruce (Picea sitchensis (Bong.) Carr.). Some hardwood stands are used. Spotted owls are most abundant in old-growth forests characterized by an uneven-aged, multilayered canopy with a high composite canopy closure. Dominant trees are large (39 inches d.b.h. or larger) and old (over 230 years) and many have broken tops, cavities, or deformed, platform-

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<sup>4/</sup>Unpublished Administrative Study Report, "A test of a spotted owl habitat suitability model," by Stephen A. Laymon, University of California, Berkeley, College of Natural Resources, Berkeley, CA 94721.



forming branches. Understory trees are 30 to 200 years old. Some of the understory trees are small, often are deciduous (such as vine maple, *Acer circinatum* Pursh.) and provide perches almost to the forest floor. Abundance of spotted owls varies with the proportion of old growth in the forested landscape. But the owls can do well in mosaics of old-growth, mature, and young stands. In extensively harvested forests, spotted owls expand their home ranges as fragmentation increases, presumably to maintain some minimum amount of old growth within their ranges. Averages (depending on area) are 1,850 to 2,265 acres of old growth per pair. Obviously, the owls cannot expand their range indefinitely (observed ranges are 1,356 to 8,349 acres); as they reach the higher limits their ability to survive and reproduce must be diminished. The average home range size in highly fragmented forests is around 4,693 acres and can be used as a basis for management. An area of 4,849 acres encompassed by a circle with a radius of 1.5 miles. Forsman and others (1984:57) felt that 88 acres of old growth within 1.5 miles of a nest tree would be adequate habitat for a pair of spotted owls, even when the remaining acreage was covered by stands less than 80 years old. The 88-acre recommendation was based on the least amount of old growth in the home ranges of the pairs of owls Forsman studied. One pair, studied for 4 months, had 1,008 acres of old growth in its home range. No other pair had less than 1,092 acres of old growth in its home range (Forsman and Meslow 1985). Habitat management for spotted owls could be based on the average amount of old growth used by pairs in the Pacific Northwest (1,850 to 2,265 acres). For example, if 2,470 acres of old growth were maintained along with stands of a variety of other ages (including 0- to 200-year-old trees) within a 1.5 mile-radius-SOMU (spotted owl management unit-habitat or one pair), the chance of maintaining a pair of spotted owls in a SOMU would be substantially improved. If use of the SOMU by a pair of owls were documented, the manager could then be reasonably confident that the SOMU was contributing to maintaining a viable population of spotted owls.

How reliable is the above information? Forsman's studies (Forsman and others 1977, 1984) and Gould's studies (1977, 1985) were based on unusually large sample sizes compared to other studies of raptors. The results of these studies were confirmed by smaller studies and by the preliminary results of two recent studies in California (Gutiérrez and others 1984, Gutiérrez 1985) and ongoing studies in Washington (Allen and Brewer 1985). But only a dozen pairs of adult owls have been studied with telemetry. Additional quantitative data will be forthcoming (Carey and Ruggiero 1985). It is unlikely that the description of suitable environments and the minimum recommendations will be lowered by forthcoming data, but data specific to a state or region are being gathered. Some tailoring of habitat management to local conditions may be possible.

## Determinants of Habitat

Why are spotted owls associated with old-growth forests in the Pacific Northwest? A number of reasons have been proposed; they can be grouped into six loosely-formulated hypotheses that are not mutually exclusive: nesting hypothesis, heat-stress hypothesis, prey-abundance hypothesis, prey-availability hypothesis, predation hypothesis, and adaptation hypothesis.

Nesting hypothesis.--Old-growth forests are more likely to contain trees that are structurally suited for nests than are young forests. The spotted owl does not construct a nest. It must therefore find natural platforms that are suited for holding the female, eggs, and young birds. Because the spotted owl is a large bird, the platform must be large. To safeguard the eggs and young from terrestrial and semiarboreal predators the nest must be high above ground. Thus the platform must be part of a large tree. Suitable platforms include large cavities in trees, depressions in the broken tops of trees, and platforms resulting from the accumulation of organic material on the fan-shaped branches of old-growth trees. This hypothesis is supported by the descriptions of the nests of spotted owls that have been found in Pacific Northwest forests (Forsman and others 1984).

Heat-stress hypothesis.--Spotted owls are intolerant (compared to many other owls) of high temperatures and are stressed at temperature above 27 to 31°C (depending on wind speed). This temperature intolerance is a function of the owl's plumage which is adapted for withstanding the stress of cold winter temperatures (Barrows 1981, Barrows and Barrows 1978). The tall, multilayered canopy of old-growth forests results in a larger gradient in temperature (and amount of direct solar radiation) than exists in forests with shorter, simple, canopy structure. The multilayered canopy provides roost perches that range from high in the canopy down to ground level. In particular, hardwoods in the understory (such as vine maple) allow roosting close to the ground. Field studies of roosting behavior and heat stress have employed meteorological equipment, radio telemetry, direct observation, and characterization of roosts and roost-stands. Owls change roosts (especially height) and body posture to avoid direct sunlight in the summer and to find ambient temperatures lower than 27 to 31°C. Stands in California used for roosting were often on north-facing slopes and in canyons. Owls in California have also been observed to change roosting locations to be near water and, when heat stress still resulted in physiological reactions (gular flutter), to bathe (Barrows 1981, Barrows and Barrows 1978). Owls in Oregon exhibit similar behavior, but unexpectedly most owls in the Coast Range roosted in stands on south-facing slopes (Forsman and others 1984). The putative association of spotted owls with old-growth stands that contain streams or seeps lends further support to the heat-stress hypothesis, as does the association of spotted owls with caves and canyons in the Southwest. Laymon (1985) observed altitudinal shifts in home range in the Sierra Nevada with the owls using

higher elevations in the summer than in the winter; the reasons for these shifts are not known at this time but the phenomenon does fit this hypothesis. The hypothesis does not explain why spotted owls are not known to occur at high elevations in Oregon and Washington.

Prey-abundance hypothesis.--Spotted owls prey on a wide variety of animals. They specialize in small mammals such as red tree voles (Arborimus longicaudus), deer mice (Peromyscus maniculatus), dusky-footed woodrats (Neotoma fuscipes), and northern flying squirrels (Glaucomys sabrinus); the latter two species are preferred--the woodrat in mixed conifer forests in California and Oregon and the flying squirrel in Washington and most of Oregon (Barrows 1985, Forsman and others 1984). A greater diversity of prey is eaten by spotted owls in the Sierra Nevada, with gray squirrels (Sciurus griseus) and birds assuming importance (Laymon 1985). Barrows (1985) has noted that owls that eat a high proportion of large prey (flying squirrels and woodrats) have greater success in breeding than do owls that eat small prey. Owls expend less energy per unit of food in capturing the large prey, thus presumably more energy is available for reproduction than when the majority of the prey is small animals. A hypothesis has been advanced that the preferred prey is more abundant in old-growth forests than in younger forests. Raphael and Barrett (1984) found small mammals, as a group, more abundant in "large timber" than in "medium timber" or "small timber." Dusky-footed woodrats and deer mice were more abundant in forests older than 250 years than in forests 150-250 years old or younger than 150 years. Both species were also abundant in shrub-sapling stages. Raphael and Barrett did not, however, adequately sample northern flying squirrels. Thus there are few data to support the hypothesis. Ongoing studies by the Forest Service (Ruggiero and Carey 1984) will answer the questions about prey abundance across the seral forest development.

Prey-availability hypothesis.--The prey-availability hypothesis differs from the prey-abundance hypothesis by stating that the prey of the spotted owl is abundant in old growth, but not necessarily more abundant there than elsewhere. The key feature is that the structure of old-growth forest is better matched to the spotted owl's size and method of foraging than the structure of younger forests and that this structure results in a greater availability of prey (more of what is there can be caught) than other environmental structures. Gutiérrez and others (1984) mention this hypothesis. Foraging perches are more available in old growth, and patchiness in the understory and gaps in the canopy may provide a better environment for foraging than do young forests. Testing this hypothesis in field studies would be difficult, but Forsman and others (1984) observed foraging behavior and documented that spotted owls select old growth for foraging. Their study lends support to the hypothesis. Gutiérrez and others (1984) reported that they had unpublished data to support the hypothesis also. Some of these data include observations of spotted owls using perches in riparian corridors and in the edges of old-

growth and mature forest to search for prey in clearcuttings and brushfields.<sup>5/</sup>

Predation hypothesis.--Great horned owls (Bubo virginianus) will prey upon juvenile spotted owls (Forsman and others 1984, Gutiérrez and others 1985, Miller and Meslow 1985); thus it is hypothesized that spotted owls use old growth or avoid open areas) to avoid predation by great horned owls. The evidence for this hypothesis is anecdotal as there is no evidence of intensive predation on adult spotted owls or that predation on juveniles is anything but opportunistic. It is generally accepted however, that dispersing juveniles of most species are especially vulnerable to predation. The apparent reluctance of both juveniles and adults to cross large open spaces like large bodies of water may reflect this vulnerability. Extensive forest fragmentation could affect the ability of juveniles to disperse successfully.

Another interspecific interaction may become important. Barred owls (Strix varia) are extending their range and are now found in western Washington, Oregon, and California. The barred owl is very much like the spotted owl, except it seems to be more versatile. The barred owl may become a serious competitor of the spotted owl (Gutiérrez and others 1984, Taylor and Forsman 1976). Harriet Allen<sup>6/</sup> has been recording sightings of barred owls and monitoring adjacent pairs of barred owls and spotted owls to determine how they interact.

Adaptation hypothesis.--The adaptation hypothesis states that spotted owls are behaviorally and physiologically adapted to old-growth forests simply because old growth has been the dominant, stable feature of the landscape for many generations of spotted owls. This hypothesis would be impossible to test. There is some evidence that spotted owls do exhibit behaviors such as site tenacity (Forsman and others 1984). Old growth may be a "niche gestalt" (James 1971) for dispersing juveniles--in other words, dispersing juveniles seek areas of a certain structure that are not occupied by adult owls and settle in such areas as a response to the structure. This response could be innate or it could reflect the owl's fledging environment.

Summary of determinants of habitat.--The various hypotheses and the supporting evidence provide a description of spotted owl life requirements that eliminate the need for terms like old-growth, mature, and young forests. It is clear that spotted owls need stands: (1) that are multi-layered with an understory (often containing

<sup>5/</sup> Unpublished administrative study report, "Winter Ecology of Radio-Tagged Spotted Owls on Six Rivers National Forest, Humboldt Co., CA," by Chuck Sisco, Humboldt State University, Arcata, CA 95521.

<sup>6/</sup> Personal communication, Harriet Allen, Washington Department of Game, 600 North Capitol Way, Olympia, WA 98504.



ardwoods), a midstory, and an overstory; (2) hat contain large (39 to 67 inches in d.b.h.) rees that contain cavities, depressions in roken tops, or platforms of large branches and rganic debris at least 33 feet above the ground; and (3) that concomitantly support abundant opulations of small mammals, particularly flying quirrels or woodrats. Large, fallen, decayed rees contribute to the abundance of small mammals Maser and Trappe 1984) and streams and seeps ould further raise the quality of the stand for potted owls. Many will equate such stands with old growth as described by Franklin and others 1981) and Franklin and Spies (1984). Franklin and others (1981) suggested that old-growth stands should be maintained in blocks of 296 to 494 acres o maintain their ecological characteristics. And hat 494 to 988 acres of old growth are needed to nfluence the character of a third-order stream rainage. Empirical data (Forsman and others 1984, Gutiérrez and others 1984) indicate that 2,470 acres will make 7.7 square miles suitable or one pair of spotted owls. The greater the proportion of the landscape in multilayered and losed-canopy stands, the greater the number of airs of spotted owls that can be maintained.

#### Managing for Viable Populations

Federal regulations direct the Forest Service to maintain viable populations of indigenous wildlife. The regulations state that a viable population is "one which has the estimated numbers and distribution of reproductive individuals to insure its continued existence is well distributed in the planning area" (MacCleery 1982). Habitat must be managed not only to maintain this minimum number but also to ensure interaction among the individuals. The key phrases in the regulations are "continued existence," "well distributed," "interact with others," and "habitat must be provided."

Continued existence of spotted owls.--Federal and State agencies plan to maintain 800-1,000 units of habitat suitable for pairs of spotted owls in northern California, Oregon, and Washington to ensure the continued existence of spotted owls. The Pacific Northwest Region of the Forest Service plans to maintain 530 of these SOMUs (Lee 1985). The adaptive management approach to managing for viable populations that is used by the Pacific Northwest Region is summarized by Salwasser and others (1984).

Two classes of factors work against the continued existence of wild populations: systematic factors are continuing or recurring events; stochastic factors are unpredictable or random changes in a species' demography, environment, or genetics and natural catastrophes (Shaffer 1981, 1985).

Systematic factors include expanding human populations, land use changes, and timber harvests. The migration of spotted owls between midelevation federal lands and low-elevation private lands in the Sierra Nevada subjects the owls to land use changes brought about by expanding human populations. Although the development is on private land, owl populations

on federal lands are affected (Laymon 1985). Systematic harvests of timber have reduced the amount of spotted owl habitat; continuing harvests in the Coast Range are jeopardizing the continued existence of spotted owls there (Carleson and Haight 1985). Land exchanges among Federal agencies and private landowners and timber harvest on private land affect spotted owls and management of spotted owl habitat on federal lands in Oregon and Washington (Ruediger 1985). Past systematic timber harvest, including timber harvests on Federal land, has jeopardized the spotted owl population of the Olympic Peninsula (Beckstead 1985, Juelson 1985). Forsman and others (1982) conclude that if the trends in timber harvest continue, spotted owls will become rare in the Pacific Northwest.

Demographic stochasticity refers to chance events in survival and reproductive success. Spotted owls suffer accidents, are preyed on occasionally, and are variable in producing young from year to year (Barrows 1985, Forsman and others 1984; Gutiérrez 1985; Gutiérrez and others 1984, 1985; Miller and Meslow 1985). The survival of juveniles from hatching, through fledging and dispersal, to establishing a territory and acquiring a mate is subject to so many chance events that it is rare (Allen and Brewer 1985, Gutiérrez and others 1985, Miller and Meslow 1985). The structure of a population (sex ratio, age structure, proportion of adults that breed) may reflect many random events.

Environmental stochasticity includes temporal variation in weather, in the owls' habitat, and in the species populations the owls interact with--prey, competitors, and parasites. Ongoing studies by the Old-Growth Forest Wildlife Habitat Program (Forest Service) are documenting marked annual variation in the population sizes and reproduction of the small mammals that serve as prey for spotted owls.<sup>1/</sup> Juvenile spotted owls are sometimes killed by great horned owls or other raptors (Forsman and others 1984, Gutiérrez and others 1985, Miller and Meslow 1985). The probability of an owl being preyed on is partially a function of the pattern of abundance of its potential predators, which in turn is a function of systematic and stochastic factors that affect the predators' populations and is due partially to chance. A potential competitor of the spotted owl, the barred owl, is expanding its population in the Pacific Northwest and may usurp some of the habitat maintained for spotted owls (Taylor and Forsman 1976, also see footnote 6). Present interactions between the two species are rare and by chance; in the future, barred owls could bring systematic pressure to bear on spotted owls. Juvenile owls leave the nest before they can fly probably because of increasing numbers of parasites in the nest (Forsman and others 1984). Leaving the nest at an early age increases the susceptibility of young owls to accidents and

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<sup>1/</sup>Unpublished data on file, Forestry Sciences Laboratory, 3625 - 93d Avenue SW, Olympia, WA 98502.



predation. Ruediger (1985) documents how unpredictable changes in habitat, such as destruction by high winds or by small wild fires, have affected the carrying capacity of the Gifford Pinchot National Forest for spotted owls.

There are no data on the genetics of spotted owls, but Barrowclough and Coats (1985) discuss spotted owl demography in the light of current genetics theory. They illustrate how chance genetic events can be of great importance when populations are small. They also point out the differences between effective population size and total population size. Effective populations (from a demographic-genetic standpoint) are much smaller than total populations.

Natural catastrophes play an important role in forest ecosystems in the Pacific Northwest. The nature and distribution of old-growth forests are results of catastrophic fires that occurred 200-1,200 years ago (Franklin and Dyrness 1973). Large areas of spotted owl habitat in the Cascade Range of southern Washington were destroyed in the early 1980's by the volcanic eruption of Mount St. Helens (Ruediger 1985). There is an interplay between systematic and stochastic factors. Systematic factors may depress population levels. At low population sizes, stochastic factors are of great importance. In at least two areas (the Coast Range in Oregon and the Olympic Peninsula in Washington) systematic factors have reduced spotted owl populations to the level where stochastic events may determine whether or not the populations persist. Indeed spotted owls have already been essentially eliminated from the Coast Range in northern Oregon and southern Washington. In other areas (northern California and the Cascade Range in Oregon and Washington) systematic factors continue to deplete spotted owl habitat and are probably a greater influence on spotted owl populations than are stochastic events. Barrowclough and Coats (1985) suggest that the 800-1,000 SOMUs (habitat for one pair) planned for the Pacific Northwest will be adequate to minimize stochastic demographic and genetic effects in a "best case" implementation scenario. Shaffer (1985) concludes that more than 1,000 SOMUs must be provided to maintain the 1,000 pairs of adult owls that he feels are necessary to minimize stochastic environmental effects. Ensuring 1,000 pairs requires more than 1,000 SOMUs because not all SOMUs will be occupied by pairs all the time.

Distribution.--Forest Service guidelines for spotted owl management incorporate requirements for distribution and interaction.<sup>8/</sup> Spotted owl management areas (SOMAs) are to provide habitat for three or more pairs of spotted owls and are to be 12 miles or less apart. Single-pair SOMAs (equivalent to a SOMU) are to be established

only to improve the distribution of SOMUs and must be 6 miles or less from other SOMUs. Implementation of the guidelines for distribution and interaction has required more SOMAs than were thought necessary for continued existence from the standpoint of population size (Beckstead 1985, Carrier 1985, Lee 1985, Ruediger 1985). These guidelines still seem reasonable in the light of additional information on spotted owl dispersal (Gutiérrez and others 1985, Miller and Meslow 1985). It is difficult however, to meet the guidelines in the Coast Range (Carleson and Haight 1985) and on the Olympic Peninsula (Beckstead 1985). The guidelines do not (and cannot) ensure interaction among all spotted owl populations. The population on the Olympic Peninsula seems to be isolated from all others by Puget Sound, extensive human development in the Puget Trough, and large areas of unsuitable habitat in the Chehalis Valley and southward. The populations in the Cascade Range in Washington may be isolated from those in the Cascade Range in Oregon by the Columbia River. Similarly, the Willamette Valley may separate Coast Range populations from Cascade Range populations in Oregon. And the guidelines do not account for stochastic environmental events, catastrophes, or chance demographic events that result in unoccupied SOMAs. The guidelines assume that SOMAs will persist indefinitely and will be occupied routinely.

Habitat.--Simply defined, habitat is the area occupied by one or more individuals of a species. The Pacific Northwest Region management guidelines (see footnote 8) define the requirements of a reproducing pair of spotted owls as 300 acres of old growth in a core area around a nest and an additional 700 acres of old growth in patches larger than 30 acres within 1.5 miles of the nest. If there is not 1,000 acres of old growth within 1.5 miles of the nest, then the oldest stands available may be substituted for the lacking old growth.

It has not been possible to locate SOMUs on the basis of actual nesting sites and home ranges; SOMUs and SOMAs have been established using crude surveys for spotted owls and old growth and to minimize land-use conflicts (Beckstead 1985, Ruediger 1985). To be effective, SOMAs must contain pairs of adult owls that fledge young from time to time. It is not safe to assume that all 1,000-acre areas of old growth (or a mixture of old-growth and mature forest) will contain a reproductively active pair of spotted owls. In general, old growth is habitat for spotted owls. But in specific instances, to be habitat the forest must contain nesting, roosting, and foraging-sites, a sufficient abundance of prey, a suitable microclimate, and spotted owls to be habitat. The 1,000-acre guideline is based on the smallest area of old growth known to support a pair of spotted owls in a heavily fragmented forest for a 4-month period; the average acreage of old growth per pair in that forest during the 4 months was over 2,000 acres (Forsman and Meslow 1985). Thus one would expect, and experience has shown, that many apparently suitable areas (as defined by the guidelines) do not contain spotted owls (Beckstead 1985, Ruediger 1985). Therefore the size and character of SOMAs must be ultimately

<sup>8/</sup>Unpublished administrative document, 1983.  
"Regional Guidelines for Incorporating Minimum Management Requirements in Forest Planning" Jeff M. Sirmon, Pacific Northwest Region, USDA Forest Service, 319 S.W. Pine Street, Portland, OR 97208.

etermined by verification procedures and monitoring (see Carey and Ruggiero 1985). One approach would be to designate more than 1,000 acres of old growth per pair until occupancy of the SOMAs has been verified and monitoring has shown that pairs are reproducing and that most spotted owl pairs can exist and fledge young with 1,000 acres of old growth.

Summary of managing for viable populations.--The accumulated information relevant to ensuring viable populations of spotted owls in the Pacific Northwest includes the following findings and conclusions:

The existing guidelines for the network distribution of SOMA's still seem reasonable in view of recent research on dispersing owls.

Original studies showed that the average amount of old growth in the ranges of owl pairs is around 2,200 acres. Subsequent studies corroborated that work.

Distributional guidelines require a network of 800-1,000 spotted owl management units. A demographic analysis concentrating on genetics concludes that 1,000 pairs of owls would be adequate for ensuring continued existence throughout the existing range only in a "best case" scenario. And a viable population analysis considering systematic and stochastic factors conclude that more than 1,000 management units would be necessary to maintain 1,000 pairs of owls. The viable population analysis is corroborated by case histories of implementation of spotted owl management plans and the preliminary results of a monitoring program for spotted owls.

Monitoring can be used to determine occupancy rates and rates of loss of habitat. The results of monitoring could be used to determine how many management areas would have to be set aside to ensure that a minimum of 1,000 pairs of spotted owls would be maintained and what margin of safety (additional management units) would be necessary to offset loss of management units to unforeseen events.

Management for viable populations of spotted owls will be effective only if there is close collaboration among land management agencies to implement a common management scheme. That situation does not exist today. State and Federal agencies have not adopted the same guidelines. The Forest Service, which manages the majority of the remaining suitable habitat, is carrying the primary burden of owl management. Also, the National Park Service, because of its mission to maintain natural environments, is protecting the spotted owl habitat on its lands.

#### ORTHCOMING INFORMATION

review of ongoing research and monitoring (Gutiérrez and Carey 1985) reveals that a significant amount of new information is being gathered on spotted owls. Research on the

seasonal movements of spotted owls in the Sierra Nevada is continuing. State wildlife agencies are compiling inventories of actively used spotted owl territories in California and Oregon and estimates of the statewide population in Washington. Habitat use by adult owls is being described in California and Washington. Breeding, reproductive attainment, and dispersal of juvenile owls is being studied in California, Oregon, and Washington. Information on the food habits of spotted owls is being accumulated throughout the Pacific Northwest. SOMA occupancy rates and spotted owl home ranges are being determined in Washington. The Bureau of Land Management is planning a monitoring study in Oregon that also will determine occupancy rates and reproductive attainment.<sup>9/</sup> In California, the Bureau of Land Management is determining the effect of timber harvesting on nearby spotted owls.<sup>10/</sup>

#### THE STATE OF WILDLIFE SCIENCE

Wildlife managers and researchers are addressing the problem of ensuring the continued existence of regional populations of species that are jeopardized by the accumulating impacts of human activities (see Lehmkuhl 1984 and Shaffer 1981). But theory and management concepts are still poorly developed. And case histories and empirical data are lacking. Theoretical constructs for defining dependencies of species on particular types of environments or elements of the landscape are not yet supported by successful application to real situations (Carey 1981, 1984; Crowley 1978; Van Horne 1983). Theories for determining the patterns of abundance (numbers, sizes, spatial distributions) of suitable environments that will maintain sufficient numbers of individuals for the species to persist despite systematic pressures and stochastic demographic, genetic, and environmental events are just being developed. Concepts for determining minimum viable populations have been proposed (Lehmkuhl 1984, Salwasser and others in press, Shaffer 1981) but not tested.

Many authors have addressed the general aspects of population genetics as related to conservation (see Schonewald-Cox and others 1983 and Soule and Wilcox 1980 for examples), but very little is known about the role genetic events play in wild populations. For this paper, I applied concepts of dependency to the problem of ensuring the continued existence of spotted owls in the Pacific Northwest. Shaffer (1985) applies the concept of minimum viable populations to spotted owl management. Barrowclough and Coats (1985)

<sup>9/</sup>Unpublished draft plan, 1984, "Northern Spotted Owl Management Plan" by the U. S. Department of the Interior, Bureau of Land Management, Oregon State Office, 825 NE Multnomah Street, Portland, OR 97232.

<sup>10/</sup>Personal communication, C. J. Ralph, Redwood Sciences Laboratory, 1700 Bayview Drive, Arcata, CA 95521.



examine spotted owl management from a population genetics standpoint. It is evident from these three papers that long-term, empirical, demographic studies will be necessary if there are to be definitive answers to questions about the viability of spotted owl populations. But the need for further development of theory and concepts is also evident.

#### INFORMATION NEEDS

Three types of studies are needed to refine spotted owl management: monitoring studies, demographic studies, and region-specific studies.

##### Monitoring Studies

The most immediate need for information is to determine how well the present management is working. Are owls using spotted owl management areas? Are the owls in SOMAs routinely producing young? What happens when the old growth in a SOMA is gradually reduced to the 1,000-acre-per-pair standard? How long does it take a vacated SOMU to be recolonized? A monitoring program to answer some of these and related questions for the SOMAs in Washington is described by Carey and Ruggiero (1985).

##### Demographic Studies

A major gap in the knowledge of spotted owl biology is spotted owl demography. What are the life expectancies of owls? At what age do owls first mate to produce young? What are the age structures of various populations? What are common rates of reproductive attainment? What are the rates of recolonization of vacated territories? What are common effective population sizes? What is the genetic diversity of the various populations in the Pacific Northwest? Is there regular exchange of genetic material among the various populations in the Pacific Northwest? How are demographic parameters affected by forest fragmentation and increased isolation of breeding pairs?

Estimates of demographic parameters can only be gained through long-term (10 years or more) studies of large numbers of owl territories (say 45-100) in each of the six major geographic areas of the Pacific Northwest. To be effective, both adult and juvenile owls would have to be banded in the study areas. During capture of the owls blood samples could be taken for genetic studies. Genetics could, thus, be a part of the study of demography. Because of the large-scale nature of the studies, they would have to be cooperative in nature. Demographic studies could capitalize on monitoring studies but it is unlikely that monitoring studies would be conducted for long enough periods to substitute for demographic studies. Demographic studies are expensive and would not provide managers with definitive information in just a few years. The information from the demographic studies would be most appropriate for building population models and for contributing to theories about minimum viable populations. The empirical data, models, and theories could then be related to management.

#### Region-Specific Studies

Most work on northern spotted owls has been conducted in Oregon and northern California. Information on habitat use that is specific to the Olympic Peninsula and Cascade Range in Washington should also be developed. Ongoing research (Allen and Brewer 1985) and a SOMA monitoring program (Carey and Ruggiero 1985), if continued, will provide the necessary regional information. Research on California spotted owls in the Sierra Nevada must continue if reasonable management recommendations are to be made for the apparently migratory populations there.

#### CONCLUSION

When the results of recent and ongoing studies are published, the information on the habitat requirements of northern spotted owls should be sufficient for management purposes. More definitive information on what constitutes the size of a viable population of northern spotted owls, however, will be available in the future once a theoretical framework for defining viability is developed. But it seems likely that no fewer than 1,000 pairs of adults will be required. Recent studies of juvenile dispersal suggest the present guidelines for distributing SOMAs should be maintained. It is unlikely that more definitive information on distribution of SOMAs can be gained through dispersal studies. The major information gap is how well present management is working. Monitoring will be essential for effective spotted owl management.

Long-term studies of spotted owls will allow development of models of viable populations. The data from these studies will however, be of limited use to managers because most decisions on the retention of old-growth and mature forests will be made before the results of such studies will be known.

Other studies will be useful. Studies on how to silviculturally create old growth or how to speed forest development will provide the information needed to replace old growth as it ages into climax forest. Studies of interactions between spotted owls and barred owls could add another dimension to the concept of viability. As with most wildlife, there are numerous aspects of biology that could be studied but that have no apparent, immediate management application. Such basic knowledge enhances management in the long term.

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## INFORMATION AND RESEARCH NEEDS FOR SPOTTED OWL MANAGEMENT

R. J. Gutiérrez

**ABSTRACT:** The information and research needs for spotted owl management are presented. The following priority list for research is given with the understanding that research needs may vary among USDA Forest Service regions and that many research topics could effectively be coordinated or conducted together. Research and information are needed on: (1) population dynamics, (2) major prey ecology, (3) habitat requirements, (4) juvenile dispersal, (5) effects of habitat modification on spotted owls, (6) inventory and monitoring, and (7) owl genetics.

The National Forest Management Act of 1976 (U.S. Laws, Statutes, etc. 1976) requires the USDA Forest Service to develop Land Management Plans (LMPs) for each National Forest. These plans will contain spotted owl (*Strix occidentalis*), management plans (SOMPs). The Forest Service is funding several studies to provide information on the basic ecology of the northern spotted owl (*S. o. aurina*) to help formulate SOMPs within the general LMPs. Because these LMPs will be completed within 2 years and then be subject to review and revision in 5-10 years, it is important that research continues on the northern spotted owl. In this paper I suggest areas of spotted owl research that will provide much of the information needed to adequately review and revise the Forest Service's LMPs.

I believe that there are some areas of spotted owl ecology that need immediate research attention. I present in this paper a list of research needs that is the result of my personal experience with spotted owls, the suggestions of this symposium's participants, and suggestions from other spotted owl research biologists. In addition, my list is

strongly influenced by discussions with Cameron Barrows, Eric Forsman, Gordon Gould, Stephen Laymon, Charles Sisco, and David Solis during an informal spotted owl workshop at Arcata, California, April 6-7, 1983. The responsibility for developing the following list, however, is my own.

### SPOTTED OWL RESEARCH NEEDS

The following suggested areas of spotted owl research are listed in my priority order. Clearly, several different research investigations may continue concurrently. It is my intention only to suggest areas of research that will provide critically lacking information on the spotted owl. I further encourage all research on the spotted owl to continue and to be shared among all interested persons.

1. **Demography:** Only the work of Forsman and others (1984) presents any substantive data on population biology. Yet it is clear from Barrowclough and Coats (1985) that demographic studies should be considered a top priority. Such information as age at first reproduction, life span, reproductive potential, and adult and juvenile survivorship will be needed to construct models sufficient to predict effective population size. This information will also be critical for evaluating the impact of environmental change on the species (Shaffer 1985).

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To my knowledge the only study currently in progress on demography is in northwestern California.<sup>1/</sup> Spotted owl monitoring in the National Forests of Washington State will also be a source of demographic data by observing changes in occupied territories (Allen and Brewer 1985, Carey and Ruggiero 1985). I suggest that most of these studies be replicated to assess geographic variation within northern spotted owl populations and among other spotted owl subspecies. It is apparent from other studies that there is geographic variation within aspects (for example, food habits) of their natural history (Gutiérrez 1985).

2. Major prey ecology: The ecology of the major prey of the spotted owl is not well understood yet prey relationships may be a major reason for the birds dependence on large areas of old growth (Gutiérrez 1985). Barrows (1985) also points out the potential relationship between owl breeding success and the proportion of large prey in their diet. Thus, it seems that both the flying squirrel (*Glaucomys sabrinus*) and wood rat (*Neotoma* sp.) warrant investigation.

Several studies are assessing the status of these animals in old growth (Raphael and Barrett 1984, Ruggiero and Carey 1984). These studies are not designed, however, to provide the most needed information on these animal's population dynamics, distribution, density, and geographic variation in abundance and reproductive success within known spotted owl territories. The study of spotted owl prey could be effectively coordinated with owl demographic studies. This could be accomplished through monitoring prey populations within known spotted owl territories. Southern (1970) successfully used this study design with tawny owls (*Strix aluco*).

Throughout this discussion I will not predict the cost or the time required to conduct these studies. The cost and time necessary to effect these studies will depend on the logistical constraints of terrain, the level of statistical precision required, and the type of research investigation (that is, population dynamics vs. habitat analysis).

Funding considerations and decisions should be made using advice from people who know the terrain and the logistical problems of sampling within a particular area.

3. Habitat requirements: The specific characteristics of habitat used by and available to spotted owls are not identified for all major areas of the owl's range. Solis (1983) provides data for northwestern California. Laymon (1985) will provide specific habitat characteristics for the northern Sierra Nevada. Yet data from mesic Oregon and Washington, arid Washington, and the

disjunct populations of *S. o. caurina* in Mendocino, Napa, and Marin Counties of California are not available. In addition, the relationship among home range size, habitat dispersion, habitat quality and reproduction is not well understood.

Habitat models are as yet lacking for the spotted owl. A U.S. Department of the Interior, Fish and Wildlife Service, Habitat Evaluation Procedure type Habitat Suitability Index Model is being developed by Salwasser and Laymon (in press). In addition a model for predicting suitable nesting habitat is being developed by LaHaye.<sup>2/</sup>

One aspect of habitat research that is very important (when trying to predict the impact of management scenarios) is quantifying the total available habitat for spotted owls. There are no published accounts that have assessed the total amount, patch size, or distribution of suitable spotted owl habitat in the Pacific Northwest. Remote sensing technology does exist for conducting such a study.

4. Juvenile dispersal: The pattern of juvenile dispersal and the success of owl dispersers are still important questions to resolve. Dispersal studies, however, are expensive research considering the resultant data. At this time I feel it is important that the study of Miller and Meslow (1985) continue for its final year. Barrowclough and Coats (1985) point out the importance of juvenile dispersal for estimating effective population size.

In addition to the study of Miller and Meslow (1985), Laymon (1985) is completing a limited study of juvenile dispersal in the Sierra Nevada in California. His studies will provide useful comparative dispersal data.

5. Effects of habitat modification on spotted owls: Much timber harvesting is occurring in known spotted owl habitat. There is ample opportunity to study the impact of timber harvesting on spotted owl reproductive, foraging, and habitat use in National Forests. Knudsen-Vandenberg Funds can be used for monitoring wildlife affected by a specific timber harvest. Within a region of the Forest Service or the Bureau of Land Management a sufficient owl sample size could be gained through regional cooperation and planning to study the impact of logging on resident owls.

Controlled experiments on the effects of timber harvesting will be more difficult to execute given the nature of commercial timber harvesting in the Pacific Northwest and the number of owl sites needed to gain a high level of statistical precision. Thus far, only anecdotal data has been gathered on the effects of timber

<sup>1/</sup> Study in progress, Alan Franklin and others, Wildlife Management Department, Humboldt State University, Arcata, Calif.

<sup>2/</sup> Study in progress, William LaHaye, Wildlife Management Department, Humboldt State University, Arcata, Calif.



investing on owls<sup>3/</sup> (for example, Forsman and others 1984, Solis 1983).

Inventory and monitoring: The Forest Service, Bureau of Land Management, and various State wildlife agencies have all conducted some spotted owl inventories. The efficiency of these efforts, however, has never been assessed. I believe owl populations were probably underestimated. Inventory was done through calling surveys, and response rates during these surveys may have been affected by time of day or year, by temperature, by reproductive condition of the owl, by territorial status of the bird, by individual variation in owl response rates, and by the number of calling episodes within an area. If spotted owl numbers have been underestimated, then the magnitude of the impact on regional populations of owls would be greater than previously anticipated by spotted owl management schemes.

Monitoring of spotted owl territory occupancy rates should be addressed to predict the effectiveness of the spotted owl management plans of the Forest Service and Bureau of Land Management (Carey and Ruggiero 1985). Allen and Brewer (1985) are currently monitoring spotted owl territories in Washington. Some of these monitoring studies could be conducted in concert with studies of population dynamics.

Owl genetics: Genetic variability in spotted owls or between spotted owl demes has never been investigated. This information may be important for constructing models of population viability and determining genetic relationships among spotted owl populations. These investigations could be conducted as part of larger studies (Barrowclough and Coats 1985). Regional coordination would be helpful.

#### ADDITIONAL SPOTTED OWL RESEARCH PROGRAMS

In this section I will mention several notable research programs that have not drawn the same attention as the Oregon and Northwestern California studies. I mention these to facilitate communication among persons interested in spotted owls. The first is the long-term investigation of Cameron Barrows at the North Coast Preserve, Branscomb, California. Barrows is continuing his prey studies presented elsewhere in this symposium (Barrows 1985) and is monitoring the long-term reproductive effort of a few selected pairs of spotted owls. Another research effort is being conducted in Washington by Harriet Allen and Larry Brewer of the Washington Department of Game. Additional studies by Allen and Brewer (1985) and Barrows (1985) are discussed above or elsewhere in this symposium (Allen and Brewer 1985, Barrows 1985). Allen and Brewer are also investigating a very important aspect of spotted owl

biology: competition and interaction between spotted owls and barred owls (*Strix varia*). In addition, the Pacific Northwest Region (USDA Forest Service) is monitoring the implementation of their spotted owl management plan. This latter investigation is headed by Bruce Marcot. Efforts are being made to design, to implement, and to coordinate monitoring of spotted owl management on Federal lands in the Pacific Northwest through a Federal interagency committee under the auspices of the USDA Forest Service's Old-Growth Wildlife Habitat Program.<sup>4/</sup>

This brief outline of research needs and research in progress has been presented to encourage spotted owl research in areas for which management agencies have specific information needs. The Old-Growth Wildlife Habitat Program of the USDA Forest Service, Pacific Northwest Range and Experiment Station, Olympia, Washington, has been serving as a clearing-house for west coast spotted owl studies. Investigators are encouraged to coordinate their efforts with that program.

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<sup>3/</sup> Unpublished data on file with R. J. Gutiérrez, Wildlife Management Department, Humboldt State University, Arcata, Calif.

<sup>4/</sup> Personal communication, A.B. Carey, Pacific Northwest Forest and Range Experiment Station, 3625 93d Ave., S.W., Olympia, WA 98502.

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## ENGLISH AND METRIC EQUIVALENTS

### Metric

1 inch = 25 millimeters  
1 inch = 2.5 centimeters  
1 foot = 30.5 centimeters  
1 mile = 1.6 kilometers

1 ounce = 28 grams  
1 pound = 453.6 grams  
1 ton = 0.907 metric ton

1 acre = 0.40 hectare

$^{\circ}\text{F} = (9/5 \text{ } ^{\circ}\text{C}) + 32$

### English

1 millimeter = 0.039 inch  
1 centimeter = 0.39 inch  
1 meter = 39.37 inches or 3.28 feet  
1 kilometer = 0.62 mile

1 gram = 0.0353 ounce  
1 kilogram = 2.2045 pounds  
1 metric ton = 1.02 tons

1 hectare = 2.47 acres  
 $^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8$





**Gutiérrez, Ralph J.; Carey, Andrew B., tech. eds.** Ecology and management of the spotted owl in the Pacific Northwest. Gen. Tech. Rep. PNW-185. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 119 p.

The spotted owl is at the center of the old-growth forest and wildlife habitat management controversy in the Pacific Northwest. There is confusion about USDA Forest Service management activities, the present state of knowledge of spotted owl biology, and what further research is needed to provide managers with the tools to ensure viable populations as mandated by the National Forest Management Act. This proceedings documents current and past management activities, current knowledge, and research needs.

**Keywords:** Owls (spotted), wildlife habitat management, research needs.

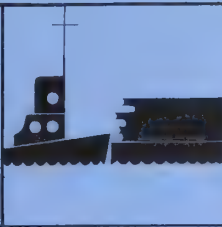
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5



# Influence of Forest and Rangeland Management on Anadromous Fish Habitat in Western North America

## **WATER TRANSPORTATION AND STORAGE OF LOGS**

JAMES R. SEDELL AND WAYNE S. DUVAL



## ABSTRACT

Environmental effects of water transportation of logs in western North America include the historical driving of logs in rivers and streams, and the current dumping, sorting, transportation, and storage of logs in rivers and estuaries in British Columbia and southeastern Alaska.

The historical discussion focuses on habitat losses and volumes of logs transported by water, both freshwater and marine. Many changes in stream-channel structure and habitat simplification still exist today, nearly 100 years after river-driving activities have ceased.

The environmental effects of current log handling on the physical habitat, water quality, plant communities, benthic and intertidal invertebrates, and fish are reviewed. Information gaps are identified and needed research is recommended.

The environmental effects of log handling are generally localized. Regional differences in intensity of aquatic and marine log transportation are discussed for Oregon, Washington, British Columbia, southeastern Alaska, Idaho, Montana, and California, to provide perspective on the volume of logs transported and areal extent of the estuarine and river habitat allocated to log transfer and storage. The most intense aquatic log handling occurs in British Columbia, Oregon, and Washington.

Guidelines and recommended practices developed in the 1970's by a west coast task force are described. These recommended guidelines minimize adverse environmental impacts.

**KEYWORDS:** Log transportation, log storage, anadromous fish habitat, plant communities, intertidal invertebrates, Pacific Northwest, southeast Alaska.

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**General Technical Report PNW-186**

**INFLUENCE OF FOREST  
AND RANGELAND MANAGEMENT  
ON ANADROMOUS FISH HABITAT  
IN WESTERN NORTH AMERICA**

**William R. Meehan, Technical Editor**

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**PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION**  
**Forest Service, U.S. Department of Agriculture, Portland, Oregon**



# PREFACE

This is one of a series of publications on the influence of forest and rangeland management on anadromous fish habitat in western North America. This paper addresses the environmental effects of water transportation and storage of logs in rivers and estuaries on fish habitat. Our intent is to provide managers and users of forests and rangelands with the most complete information available for estimating the consequences of various management alternatives.

In this series of papers, we will summarize published and unpublished reports and data as well as the observations of scientists and resource managers developed over years of experience in the West. These compilations will be valuable to resource managers in planning uses of forest and rangeland resources, and to scientists in planning future research.

Previous publications in this series include:

1. "Habitat requirements of anadromous salmonids," by D. W. Reiser and T. C. Bjornn.
2. "Impacts of natural events," by Douglas N. Swanston.
3. "Timber harvest," by T. W. Chamberlain.
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12. "Rehabilitating and enhancing stream habitat: 1. Review and evaluation," by James D. Hall and Calvin O. Baker.
13. "Rehabilitating and enhancing stream habitat: 2. Field applications," by Gordon H. Reeves and Terry D. Roelofs.
14. "Economic considerations," by Daniel D. Huppert, Roger D. Fight, and Fred H. Everest.

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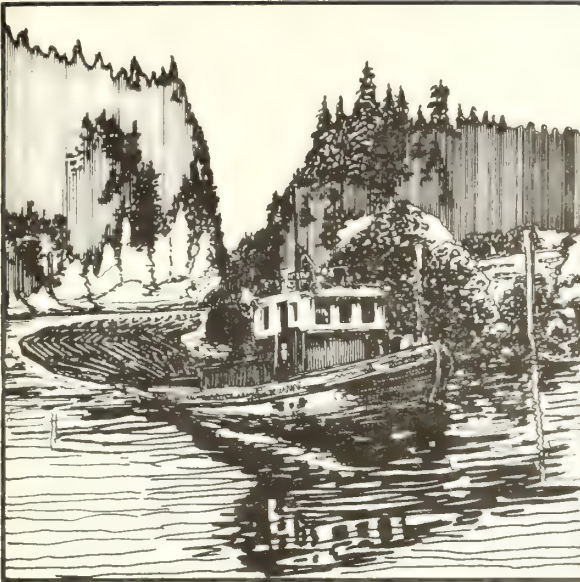
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## COMMON AND SCIENTIFIC NAMES OF FISHES MENTIONED IN TEXT AND TABLES 1/

Common name	Scientific name
Herrings	FAMILY Clupeidae
Trouts	FAMILY Salmonidae
Pink salmon	<u>Oncorhynchus gorbuscha</u> (Walbaum)
Chum salmon	<u>Oncorhynchus keta</u> (Walbaum)
Coho salmon	<u>Oncorhynchus kisutch</u> (Walbaum)
Sockeye salmon	<u>Oncorhynchus nerka</u> (Walbaum)
Chinook salmon	<u>Oncorhynchus tshawytscha</u> (Walbaum)
Cutthroat trout	<u>Salmo clarki</u> Richardson
Rainbow (steelhead) trout	<u>Salmo gairdneri</u> Richardson
Dolly Varden	<u>Salvelinus malma</u> (Walbaum)
Smelts	FAMILY Osmeridae
Surf smelt	<u>Hypomesus pretiosus</u> (Girard)
Capelin	<u>Mallotus villosus</u> (Müller)
Longfin smelt	<u>Spirinchus thaleichthys</u> (Ayers)
Eulachon	<u>Thaleichthys pacificus</u> (Richardson)
Codfishes	FAMILY Gadidae
Surfperches	FAMILY Embiotocidae
Shiner perch	<u>Cymatogaster aggregata</u> Gibbons
Ronquils	FAMILY Bathymasteridae
Searcher	<u>Bathymaster signatus</u> Cope
Clinids	FAMILY Clinidae
Combtooth blennies	FAMILY Blenniidae
Sand lances	FAMILY Ammodytidae
Pacific sand lance	<u>Ammodytes hexapterus</u> Pallas
Scorpionfishes	FAMILY Scorpaenidae
Rockfish	<u>Sebastes</u> spp.
Sculpins	FAMILY Cottidae
Righteye flounders	FAMILY Pleuronectidae
Yellowfin sole	<u>Limanda aspera</u> (Pallas)

1/From "A List of Common and Scientific Names of Fishes from the United States and Canada," American Fisheries Society Special Publication 12, Fourth Edition, 1980, 174 p.





## INTRODUCTION

Transportation is one of the major problems facing the entrepreneur in the lumber industry. In 1913, Bryant (p. 121) hypothesized that the "transportation of forest products to mill or market represents 75 percent or more of the total delivered cost of raw material, exclusive of stumpage value." Log transportation and stumpage acquisition and value are still the two major costs before the mill processes. Logs have always been considered a heavy, bulky, and cheap commodity that could not stand expensive transportation charges. Those successful in the lumber industry had to become specialists in transporting logs over the long distances that separated the primary producer and the consuming market. Indeed, the transportation of logs is still one of the central pivots around which success or failure of a lumbering operation revolves.

In the past, transporting the logs inexpensively was the industry's biggest concern. Only in the last decade has concern for aquatic or coastal marine environments been a main consideration. In earlier days, river navigation and sawmill waste resulted in environmental changes that are still detectable. Present environmental concerns over log handling in coastal waters are well documented for intertidal areas but less so for subtidal environments.

Environmental impacts of water transportation of logs in western North America can be divided into the historical driving of logs in rivers and streams, and the current dumping, rafting, and storage of logs in rivers and estuaries in British Columbia and southeastern Alaska.

The historical perspective focuses on habitat losses and volume of logs transported by water, both freshwater and marine. Many changes in stream-channel structure and habitat simplification still exist today, nearly 100 years after river-driving activities have ceased.

The current environmental concerns in British Columbia and southeastern Alaska, as well as in a few locations in Oregon and Washington, draw extensively on excellent summaries, reviews, and task-force reports from both Canada (Duval and others 1980) and the United States of America (Hansen and others 1971).

The objectives of this paper are to: review and describe historical log transportation in rivers, which was extensive in the western United States and eastern British Columbia; provide a perspective on the volume of logs transported and areal extent of the estuarine and river habitat allocated to log transfer and storage; and describe the environmental impacts of log transfer and storage that relate to fish habitat.

## HISTORICAL LOG TRANSPORTATION

Numerous books have described the history of the timber industry, and many articles have glorified log drives on rivers. Only one significant book (Rector 1953) has been published on the extent and role that water transportation played in the early days of the timber industry. A book-length

manuscript<sup>1/</sup> was produced from research undertaken for the State Lands Division of Oregon, in which the extent of navigation was determined for each of Oregon's river basins. Each of the 23 basin studies was issued as a navigability report from the State Lands Division in Salem. These two documents record the extent, duration, and dependence on water for log transportation.

The first sawmills on the west coast, between 1840 and 1870, were supplied with logs from trees that had grown at the edge of bays or large rivers. The trees were felled directly or rolled into the water, and the logs were then floated to the mills (Cox 1974).

By the early 1880's, the best timber within 2 miles of the entire shoreline of Hood Canal had been cut (Buchanan 1936). The same was true of most other readily accessible areas. Loggers constantly sought out streams along which the timber had not yet been cut. If a stream was large enough to float logs, it was soon in use. A newspaper (The West Shore 1883, p. 128) announced in 1883 that in Columbia County, Oregon, every "stream of any size has been cleared of obstructions, so that logs can be run down them in the high water season." By the end of the 1880's the same was true of almost any county along the lower Columbia, around Puget Sound, or along the "lumber coast" (Cox 1974). The centers of the timber industry reflected this dependence on water (fig. 1).

Historically, the lumber industry in the Pacific Northwest had its markets in San Francisco, San Diego, and the Pacific Rim countries. The industry depended on markets reached by sea. Thus, mills were located at seaports or

<sup>1/</sup>Personal communication, James E. Farnell, Division of State Lands, Salem, Oreg.

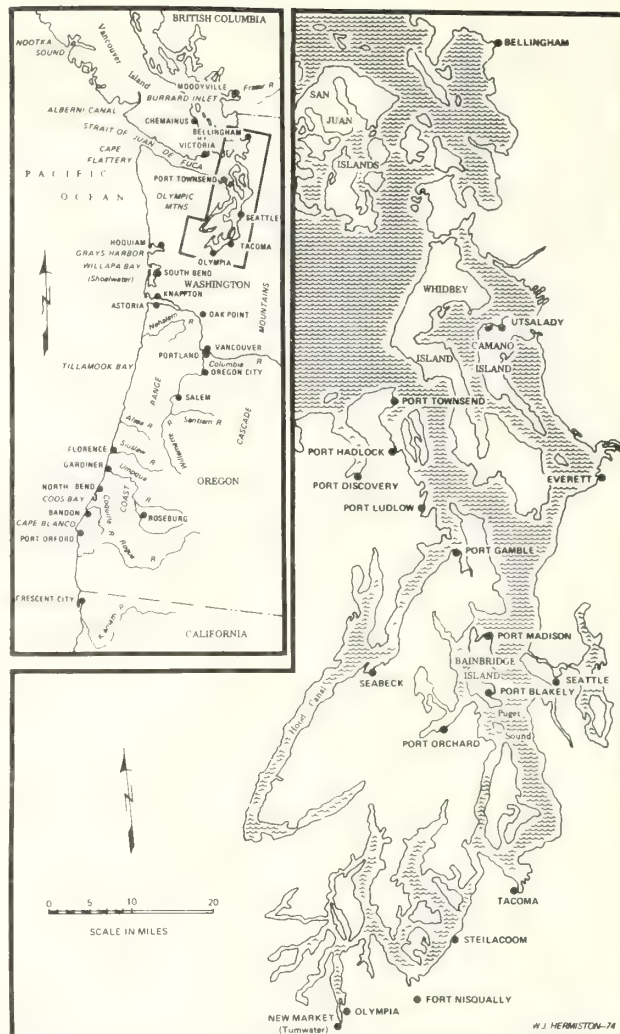


Figure 1.--Lumber centers of the Pacific Northwest before 1900 (from Cox 1974).

along the lower Columbia River (Cox 1974). Many of these early lumber centers had disappeared by the turn of the century. The big lumber centers today are still usually located where they can service both rail and sea cargo markets.

## COMMERCE CLAUSE AND NAVIGABLE STREAMS

From the earliest days, efforts to improve streams have encountered legal difficulties. To keep mill owners and farmers from blocking the rivers with dams and other obstructions, a stream had to be declared navigable. In



Michigan, Wisconsin, and Minnesota, the courts decided that a stream that could float a saw log was a "public highway" and that saw logs had just as much right to be on the rivers as rafts, barges, and steamboats. Navigable streams were not to be blocked by bridges, piers, fences, or duck ponds. At the same time, lumbermen were not to build storage and splash dams without special legislative permission (Rector 1953).

The United States Government transferred ownership of the beds of the navigable waterways to a State when it entered the Union. To ascertain which riverbeds were transferable, the U.S. Supreme Court defined a navigable river as:

Those rivers must be regarded as public navigable rivers in law which are navigable in fact. And they are navigable in fact when they are used, or susceptible of being used, in their ordinary condition, as highways for commerce, over which trade and travel are or may be conducted in the customary modes of trade and travel on water. (The Daniel Ball 1870)

Washington, Oregon, and California all must in general comply with this definition of navigable waters.

In Washington, any stream capable of successfully floating logs was considered a floatable stream, and the logger had a right to use its waters to float logs toward the mill or market. Even though a stream was completely incapable of such log floating during the dry season, its waters were public if natural freshets provided enough water to float logs. If the stream was reasonably capable of navigation by boats or canoes and commerce was carried on, then the State owned the streambed. If the stream was floatable, but not navigable in the usual commercial sense, then the adjoining landowner or owners owned the bed of the stream. In both instances, the waters were public and the public could use them. The State had exclusive control of these so-called floatable waters. The United States Government had overriding control of

truly navigable waters although the States had jurisdiction. Streams too small to float timber were considered private, and loggers probably would not use such streams unless they owned them. Thus, the logger had no right over the objections of the riparian owner to put in roll dams to cause backwaters or splash dams to create artificial freshets. The boom and driving companies were able to obtain the right to drive a floatable stream because they were quasi-public corporations (Bridges 1910). As such, they had the power of eminent domain and could run their splash dams by condemning the property and paying in advance to every landholder adjoining the stream.

Even though litigation frequently resulted, most streams in western Oregon and Washington were used for log drives.



## LOG DRIVES AND RIVER IMPROVEMENTS

Log driving is the process of transporting logs by floating them in loose aggregations in water with the motive power supplied by the natural or flushed streamflow. At first, all timber within easy access of the stream was cut and floated down the adjacent river. If timber was too far away to be profitably hauled by oxen to the mill or stream, the logger moved to another



location. Gradually, loggers had to go greater distances for timber, which introduced the use of river landings, log yards, log driving, rafting, towing, and booming (Rector 1949). Still later, the more distant timber required the use of splash dams and sluiceways, expensive stream improvements, canals, tramways, trestles, log chutes and slides, trucks, and railroads for floating and driving.

As more logs were needed, artificial freshets were created by splash dams. A splash dam was a device for turning tiny streams into torrents large enough to float logs. A dam would be built on a stream and water stored behind it. When a large head of water had been accumulated, it would be released and would quickly sluice logs that had been dumped into the pond behind the dam--together with others collected along the watercourse below the dam--to where they could be handled by conventional means.

Streams of all sizes had to be "improved" before a log drive could begin. Principal forms of stream improvement were (Brown 1936):

- Blocking off sloughs, swamps, low meadows, and banks along wider parts of the streams by log cribbing to keep the logs and water in the main stream channel.
- Blasting out or removing boulders, large rocks, leaning trees, sunken logs, or obstructions of any kind in the main bed during periods of low flows. Obstructions or accumulations of debris--such as floating trees, brush, and rocks--often caused serious and expensive log jams during the driving seasons. Frequently, small, low-gradient streams were substantially widened during log driving, as a result of the frequent flushing of the stream by splash dams and by the impact of the logs along the streambank.

The historical methods of stream cleanup and improvement in the Pacific Northwest were determined from interviews with pioneers, county court

records, State court records, and U.S. Army Corps of Engineers reports. An example is from the Samish River, Washington, in 1880, as told by E. E. Watkinson:

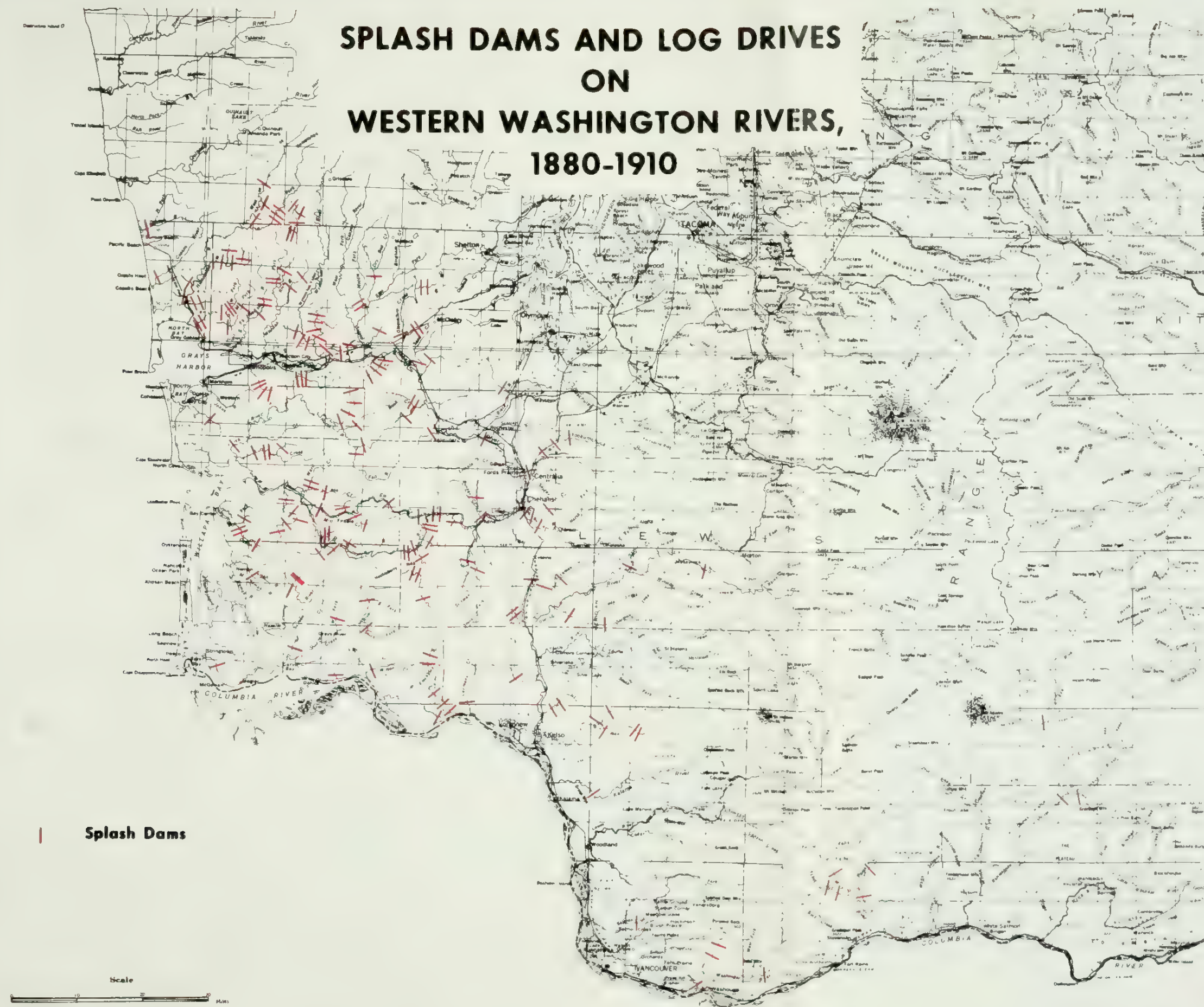
Since no logs had ever been driven down the Samish River before, E. E. and Milbourne Watkinson began the backbreaking task of cleaning out the river which was then a network of sloughs, islands and jams with no main channel. For the purpose several Indians were hired. Islands were cleared of brush which was towed ashore on a slab raft and burned. During this campaign the river was cleared from about 2 miles above Allen to saltwater. (Jordon 1962)

The length of river was just a few miles and took 4 months to clear.

Court records also give good accounts of activities to clear obstructions on different rivers and streams. East Hoquiam Boom and Logging Company vs. Charles Nelson and others (1898) describes the continued improvement of the stream ". . . by removing fallen trees, snags, roots, jams of logs and other obstructions . . ." from the ". . . narrow, crooked streams varying in width from forty to a hundred and fifty feet and containing numerous shallows and sandbars" (p. 143). "It also appears that the annual expense of keeping the streams clear of obstructions, so as to enable the logs to be floated, thereon, between plaintiff's upper dam and tide water, amounts to hundreds of dollars" (p. 145).

By 1900, over 130 incorporated river- and stream-improvement companies were operating in Washington. The distribution of major splash dams in western Washington and western Oregon is illustrated in figures 2 and 3. Over 150 major dams existed in coastal Washington rivers, and over 160 splash dams were used on coastal and Columbia River tributaries in Oregon. The splash dams shown represent only the main dams that operated for several seasons. On many smaller tributaries, temporary dams

# SPLASH DAMS AND LOG DRIVES ON WESTERN WASHINGTON RIVERS, 1880-1910



JPD 1981

Figure 2.--Splash dams operating on western Washington rivers from 1880 through 1910 (from Bryant 1949, Wendler and Deschamps 1955, and U.S. Army Corps of Engineers reports on file at Portland District Office).



# **SPLASH DAMS AND LOG DRIVES ON WESTERN OREGON RIVERS, 1880-1910**

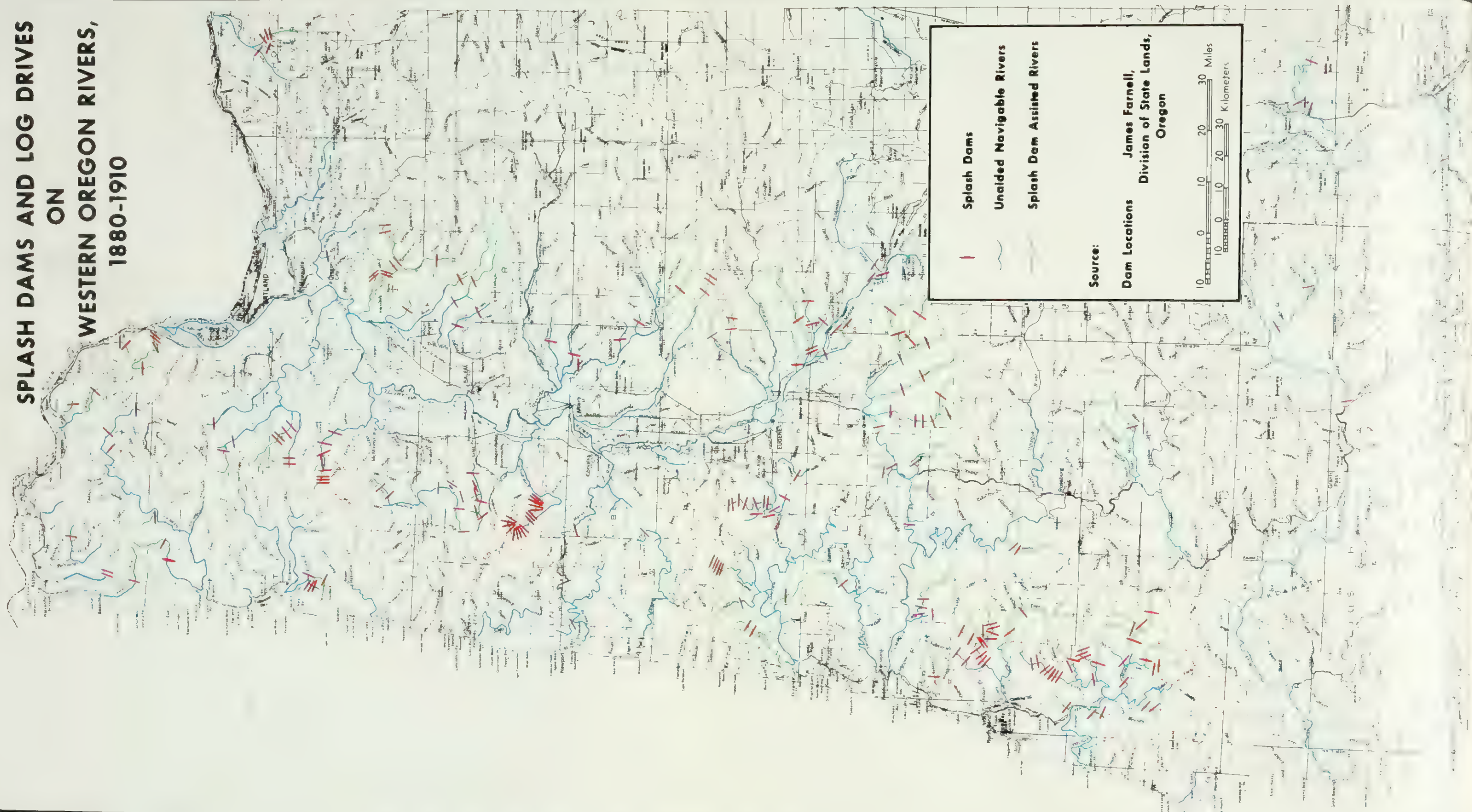


Figure 3.--Splash dams operating on western Oregon rivers from 1880-1910 (some on the Coos Bay rivers operated until the mid-1950's). Data were derived from research and reports by Dr. James E. Farnell of the Division of State Lands, Salem, Oregon.



were used seasonally, but no records were kept. Wendler and Deschamps (1955) were mainly concerned with these dams as obstacles to fish migration. Many were actually barriers, but the long-term damage was probably caused by the stream improvement before the drive and the scouring, widening, and unloading of main-channel gravels during the drive.

Small streams were heavily impacted by logging of cedar (Thuja plicata Donn ex D. Don), which occurred many years before clear-cut harvest. Because cedar was used for shingles and not just for lumber like Douglas-fir (Pseudotsuga menziesii (Mirb.) Franco), it could be cut up into small bolts (<1-m lengths). They could then be driven down very small streams. "By taking out shingle bolts from inaccessible localities far from the mills and driving them down streams impossible for logs, it is possible to utilize overmature cedar that would deteriorate before general logging on the tract was possible" (West Coast Lumberman 1914). Much of the best and most plentiful cedar timber occurred along streams in Puget Sound and in rich, moist, coastal valleys; it was exploited more rapidly than Douglas-fir. Even for driving cedar bolts, small streams had to be cleared of fallen trees, big boulders, and vegetation rooted in the channels. Streams were maintained clear of obstructions until the cedar logging in the drainage was completed.

To maintain unimpeded navigation of logs and commercial barges, snag boats operated on Puget Sound streams from 1890-1978. During this period, about 3,000 snags a year were removed from a total of 322 km of stream length in the Skagit, Nooksack, Snohomish, Stillaguamish, and Duwamish Rivers. In 1890, Coquille County in Oregon authorized a public snagging operation on the Coquille River system that continued until the early 1970's.

Clearing of streams and rivers for passage of boats and logs has reduced the interaction of the stream system with its flood-plain vegetation. Draining, ditching, and diking of valley bottoms and lowlands has also reduced terrestrial-aquatic interaction. Flood-control levees have reduced or eliminated complex sloughs and side channels, which are valuable rearing areas for salmonids (Sedell and others 1980).

River improvements and log drives on coastal Oregon and Washington rivers and rivers on the west side of Puget Sound strongly affected the estuaries. When large, natural debris dams were cleared out of the lower Nooksack in the mid-1880's, the resulting flush of channel sediments filled Bellingham Bay over a kilometer (U.S. Congress 1892). Sediments from cleanup activities transported by the Siletz River filled Siletz Bay between 1905 and 1923 (Rea 1975). River snagging resulted in an unloading of sediments from the main channel and a deposition in the bays below. All coastal Oregon and Washington rivers reflect a lack of improvements for log drives.

Along the arid west central coast of California, rivers and streams also supported log drives. In western Nevada, from 1853 to 1914, over 64 sawmills operated on sections that are now relatively treeless. Billions of board feet of timber were driven down the Truckee, Carson, and Walker River systems for lumber, firewood, and other uses related to the development of the silver mines around Virginia City (The Timberman 1941). Many of the mining and smelting activities in Arizona, Montana, Utah, and Colorado in the late 1880's depended on stream transportation of logs. The transcontinental railroads required large and continual supplies of railroad ties, which were not preserved with creosote in those days. The demand was met by logging watersheds adjacent to the railway and driving the logs down streams that intersected the line (Brown 1936).

The rivers in the more arid parts of the United States also had to be improved before log drives could begin. Marble Creek on the St. Joseph River in Idaho is one example. Blake (1971) described the numerous debris jams that had been there for many years. In a 29-km stretch ending at Homestead Creek, over 500,000 board feet of good timber were recovered from the stream channel. An additional large amount of wood was used to fuel the steam donkey's trip up the canyon to Homestead Creek. Blake and his companions also "... pulled over and sawed any trees standing on the bank which might fall and cause a jam while the drive was on" (p. 73). Fishing was described as excellent on this stream before the drives. "Fifteen minutes after we moved through a deep hole, we could catch 6 or 8 large trout there. I have never seen trout fishing, from Canada to California, half as good as the fishing on the Marble Creek before the log drives" (Blake 1971, p. 73). This is probably a "fish story" to some extent, but the fact remains that large trout were not there after the log drives.

In Alaska and western British Columbia, log drives were not common in the history of logging or stream degradation. Log drives in the Yukon, Chena, and Tanana Rivers and tributaries have been well documented; in particular, they supplied timber during the gold rush in the early 1900's. Fraser River, British Columbia, tributaries were driven extensively from 1910 to 1946. A log drive in 1965 on the Stellako River was the only one ever studied from a fish-habitat point of view (International Pacific Salmon Fisheries Commission 1966).

All of these rivers had to be improved in one way or another. Blasting boulders and pulling debris and snags was usually all that was needed on the larger streams. Throughout the West, the story was the same: sloughs and backwaters were closed off, pools were filled, and pools above rapids were lowered by blasting. The gradients of the streams were evened out and habitat complexity was lost.

Ironically, the attitude of "river improvement" from the old log-driving days has been a common theme of fisheries management until recently. Debris-jam removal and snagging for navigation and fisheries reasons have resulted in the long-term loss of thousands of miles of streams in the western United States (Sedell and others 1982, Sedell and Luchessa 1982). River-salvage logging and snagging the lower ends of rivers in Oregon, Washington, and Alaska continue on a large scale today. The salvage results in loss of the habitat complexity essential for both spawning and rearing of salmonids. Many philosophies carried over from log transportation and navigation days need to be overcome if we are to have an effective plan for protecting salmonid habitat.

## EFFECTS OF LOG DRIVING ON SALMON POPULATIONS

### SCOURING AND FLOW MANIPULATION

During early development of logging in the Pacific region of the United States, log driving in many streams with insufficient flow required periodic releases of water from splash dams. These surges of water and logs eroded streambeds, gouged banks, straightened river channels, and prevented fish from spawning. Eggs previously deposited were subject to heavy losses by scouring and silting, or by the reduced flow when the splash dam was closed. In addition, rearing areas for stream-dwelling species--such as coho and chinook salmon and trout--were largely destroyed.

Over 150 splash dams were installed in the Gray's Harbor-Willapa Bay area of southwestern Washington alone (Sedell and Luchessa 1982). The effects of these operations on salmon runs were described by Wendler and Deschamps (1955, p. 2) as follows:

The actual splashing of a dam affected fish in several ways. If fish were spawning, the sluiced logs and tremendously increased



flows would drive them off their nests. On the day prior to the splashing of one of the large Stockwell dams on the Humptulips River, an observer had noted a large number of steelhead below the apron of the dam. After splashing, no fish were seen, nor were any seen the following day.

Besides harming the fish, splashing often adversely affected the stream environment. Moving logs gouged furrows in the gravel, and the suddenly increased flows scoured or moved the gravel bars, leaving only barren bedrock or heavy boulders. New stream channels were constantly being created and the existing ones changed. If the sudden influx of logs into the stream below the dam caused a log jam, as often happened, dynamite or black powder was used to clear the obstruction. In those days the policy seems to have been that if two boxes of powder would suffice, four were used. On some areas below dams in the lower Humptulips region, an average of five boxes of powder a day were used to break up log jams. Great numbers of salmon and steelhead trout were reportedly killed by these blasts.

Dam operators have stated that fish runs reaching the dams were reduced within 3 to 4 years after the initial construction, and they recognized that splashing deleteriously affected spawning below the structure. When splashing was done because of economic conditions and flow was normal below the dams, operators claimed that spawning was more successful as evidenced by increased runs in the next cycle.

The streambed was gouged by logs even though flows provided by splash dams presumably were adequate for log transport. In addition to damage from periodic surges of water, the logs themselves appear to have contributed to streambed damage and the reported decline in salmon runs.

Similar logging practices were employed in western Oregon on all coastal streams. The Coquille River had ten logging dams and innumerable log jams were created by logging debris. "Splash dams in the Coos and Coquille systems, built for the purpose of sluicing logs down the rivers, blocked the salmon runs and eliminated the productivity of the streams above them. This practice has also resulted in the sluicing of the gravel and destruction of the spawning area below the splash dams" (Gharrett and Hodges 1950). A study of the effects of logging on coho salmon production of the Coquille River showed a significant relation between production of lumber in Coos County (in which most of the Coquille River lies) and the catch of coho salmon 6 years later; high lumber production was generally followed by a decrease in the catch (McKernan and others 1950). This relation did not exist in an adjacent county where logging was less extensive.

The history of sockeye salmon runs to Lower Adams River, tributary to the Fraser River in British Columbia, provides an exceptional example of the effects of log driving on salmon. A typical splash dam, operated at the upper end of the river, sent surges of water and logs over spawning grounds used by large numbers of sockeye. One early observer (Baldrige 1916) recorded the following impression of this operation:

When I arrived at the head of Adams River, or the mouth of Adams Lake, I found a large dam across the river. I found a fish ladder in it, and it was in good shape. This dam is used for splashing thousands of logs down the river in such a manner that without doubt it causes a great destruction of spawn in the Adams River.





The operation of this dam was of considerable concern to the fishery overseer; he reported that even when he tried to avoid the adverse effects of sudden releases of water, considerable damage was done to spawning areas (Shotton 1926a). In the drive started on November 13, 1926, a special effort was made to keep the flow high enough to prevent logs from dragging on the gravel beds. By November 19, the pole drive (5,500 logs) had reached the lower end of the Adams River, and poles were raking the spawning areas so badly that the fisheries guardian is reported to have left the river in disgust. In a subsequent assessment of the drive, the overseer (Shotton 1926b) reported as follows:

The last mile was the scene of many jams and this is where the most damage was done both by the men tramping over the shallows and the poles raking almost every foot of that part of the river. It is almost impossible for the Guardian or myself to estimate the amount of damage done as there is no practical way of making such an estimate. The time occupied in the last mile was seven days, that in itself gives you some idea of what damage was done.

Thompson (1945) concluded that manipulation of river flow by the dam had adversely affected the Adams River sockeye run and most probably had caused the decline in this run observed after 1913. Subsequent increases in the sockeye population and the shift in dominance from the 1925 to 1961 cycle to the 1926 to 1962 cycle were attributed to the return to normal flow conditions in 1922. Here again, distinguishing the damage caused by surges of water from that caused by logs gouging the river bed and driving fish out of the river was impossible.

Following a survey of the Lower Adams River and the splash dam in 1940, Bell and Jackson (1941) observed that:

The effects of driving logs down a salmon stream are illustrated well in the Adams River. Bars and shallows are deepened and pools are filled due to gouging of the bottom. Curves on the course are straightened by the impact of floating logs and the stream tends to become a swift straight raceway of uniform depth and velocity. When driving ceases, the river begins a return to the natural conditions, but the process is slow. Eleven years later the Adams River still shows markedly the alterations due to the movement of logs.

Most of the splash dams were temporary, and were abandoned after timber in the immediate vicinity had been removed. Of the 139 dams reported in Washington, 53 washed or rotted out, and 44 were later removed at the expense of the fishery agencies (Wendler and Deschamps 1955). The Lower Adams River dam was removed by the International Pacific Salmon Fisheries Commission in 1945 after being unused for more than 15 years.

The modern method of transporting logs from the forests to mills or shipping points is by trucks, using public or private roads. As a consequence, log driving is no longer common. No log drives are occurring in the rivers of Washington or Oregon, nor in any California streams used for spawning. The Clearwater River in Idaho was used for log driving until the late 1960's, but little spawning (steelhead trout) takes place in the affected part of the river.

In its brief to the Sloan Commission on Forestry, the Department of Fisheries of Canada (Whitmore 1955) summed up the effects of log driving and concluded that driving in shallow rivers had caused extensive damage in the past and still remained a threat to the salmon fishery. In addition to the destruction caused by gouging of gravel spawning bars and resultant channel erosion, construction of so-called "river improvements" created further dangers to salmon spawning and incubation by disrupting the normal regime of the river. "Stranded logs may divert water flow from gravel bars, resulting in drying out of deposited spawn, or diversion of normal water flows from potential spawning areas" (Larkin and Graduate Students 1959).

## BARK LOSSES AND DEPOSITS

Much of the bark on logs is knocked off during a drive, either by contact with the stream bed or bank, or by contact with other logs. About one-third of the bark was removed from logs driven down the Stellako River (International Pacific Salmon Fisheries Commission 1966). Vladykov (1959) reported that about 40 percent of the bark was removed during pulpwood drives in Quebec, and several tons of bark were deposited in some rivers each year. Because of this deposition, spawning areas may be reduced and rich food-production areas may be completely smothered. McCrimmon (1954) concluded that bark deposits not only reduce spawning area, but also destroy the shelter for salmon fry, making them more vulnerable to predators.

In northern British Columbia, logging was carried on during the winter when the ground was frozen and roads remained passable. Where water transport was to be used, logs were stored until the waterways were open. Although bark on these winter-cut trees was more securely attached than on trees cut in summer, it became waterlogged and was easily removed if the logs were stored in water. When dislodged, the bark sank to the bottom as observed on both the Nadina and Stellako Rivers (International Pacific Salmon Fisheries Commission 1966).

## RIVER IMPROVEMENTS

Rarely can logs be driven down a river without some form of "improvement" at difficult spots to prevent permanent stranding or jamming. Even in a large river such as the Fraser near Quesnel, British Columbia, booms had to be constructed to direct logs away from certain areas (International Pacific Salmon Fisheries Commission 1966). In the Quesnel River, projecting rocks have been removed to prevent log jams, and some side channels have been closed to prevent loss of logs in shallow water. This practice was common on all rivers in Oregon and Washington from the 1860's to the 1920's. In Washington, over 300 river- and stream-improvement companies were registered from 1898 to 1948. Over 75 percent of these companies were registered between 1898 and 1920. In the Stellako River, a new channel was made near the lower end of the river, diverting flow from the original channel and destroying spawning grounds in 200 to 300 m of river length. The new channel was reported never to have been productive; it changed the hydraulic structure and reduced the amount of suitable spawning ground for about 500 m upstream from the new channel (International Pacific Salmon Fisheries Commission 1966).



The Department of Fisheries of Canada (1964) reported that channeling on the Kitsumgallum River, British Columbia, did not stabilize the river bed because, as the flow was directed from one place, it scoured others. During the log driving (now discontinued) on this river, the logging company continually made requests for further river improvements and, in some instances, had to repair or rebuild previous work.

Despite construction to facilitate log driving, stranding of logs remained a major problem. Concerning the Kitsumgallum River, the Fishery Officer reported: ". . . stranded logs that piled up on the spawning riffles changed the river flow and velocity on these bars with resulting scouring in some places and stranding in others" (International Pacific Salmon Fisheries Commission 1966).

Salvage of stranded logs is an inevitable feature of river log driving. Salvage may require river boats and manpower, dynamite to break up jams, or bulldozers to push logs back into the river. Such operations cause breakdown of the river banks and gouging of the stream bed, as well as disturbances--sometimes lethal--to fish and eggs.

## **MAJOR PHASES OF LOG HANDLING IN THE COASTAL WATERS OF BRITISH COLUMBIA AND SOUTHEASTERN ALASKA**

In both southeastern Alaska and western British Columbia, geography and lack of roads have required the use of coastal marine and riverine waters for log storage and transportation. Log-handling and storage facilities that require water are: log-transfer sites for individual timber sales; log-raft formation and storage areas near the timber sale; winter log-raft storage areas; and storage and sorting areas near the mill.

The major phases of log handling have been reviewed in detail by Boyd (1979), Duval and others (1980), and Forest Engineering Research Institute of Canada, Western Division (FERIC) (1980) for British Columbia and by Beil (1974) and Forest Engineering Incorporated (1982) for southeastern Alaska. The different methods used--as well as the economics of alternative methods of dumping, sorting, booming, and transporting--are fully discussed in these reviews.

Logs are transported from the land-water transfer site or "dump" to sorting and booming grounds. They are then towed in booms to storage areas or transported on barges to dumping sites. From barge dumping sites or central sorting sites, logs are sorted, boomed, and stored; they are then towed to mill storage sites and finally to the processing facility.

Many combinations of methods have been and can be applied to any of the four major log-handling processes.

### **DUMPING**

Methods of dumping include:

- Vertical hoist method, such as A-frame, ginpole, and parbuckle.
- Crane.
- Equipment watering, using a cat, skidder, or front-end loader.
- Slide ramp.
- Cable carriage.
- Self-tipping barges.

### **BOOMING**

Historically, many kinds of rafts and booms have been used. Two basic types are currently used:

- Flat raft--logs are stored and towed loose inside a series of channel boomsticks. These rafts cover about 0.4 ha. In Canada, the rafts are divided into sections each about 21 X 21 m; each section holds 15 to 101 thousand board feet. Rafts of up to 30 sections are common.



- Bundle booms--logs are bundled loosely with wire or metal bands. Bundles range from 3 to 45 thousand board feet and usually draw 1.5 to 2.5 m of water. The bundles are stored and rafted similar to the flat rafts. A raft of bundles contains a log volume of 300 to 600 thousand board feet.

Log bundling is the preferred method for reducing log losses and making the sorting process more economical and efficient.

## STORAGE

Marine storage can be either intertidal, shallow, or deepwater. Logs are often stored near freshwater inflows to reduce shipworm infestation, although the degree of protection this technique affords depends on factors such as salinity, currents, storage time, and season. Reduced storage time is probably the most efficient means of reducing shipworm damage.

## TRANSPORT

Methods of transport include rafting with flat rafts from which log loss is high and which is limited to calm inside waters, and rafting with bundles, which reduces log loss and is less limited by weather in exposed areas. Barging is a common method of transportation in British Columbia because barges can be operated year round in exposed areas and because high volumes of logs pass through few sites. These barges can be self-dumping, self-loading, or both, and the logs can be barged either loose or in bundles.



Barge-mounted cranes capable of handling 22 bundles of 88 tons each have been developed and should reduce barging and dumping of loose logs.

The principal activities that may affect the marine environment are limited by economic and operational requirements to lands that are adjacent to water and that have acceptable combinations of geophysical and morphological features. Duval and others (1980) summarized the typical location and required conditions for each phase of log handling. These conditions are indicated in table 1.

Table 1--Typical conditions for log handling on British Columbia coastal waters and adjacent land

Log-handling phase	Minimum depth of water, meters			Estuaries			Bays and sheltered reaches			Exposed shoreline	
	0-4.5	4.6-7.5	Over 7.5	Muddy shore 0-20% slope	Mud to gravel 20-40% slope	Rocky shore 40-80% slope (deep water)	Tidal marshes Muddy shore 10% slope	Gravel shore 10-40% slope	Rocky shore 40-60% slope (deep water)	Gravel 10-20% slope	Rocky 20-50% slope (deep water)
Skidding (not common)											
Skidding onto beach	X				X	X		X		X	
Yarding into water									X		
Tractor pushing					X			X		X	X
Dumping											
Lift and lower bundles	X	X		X		X		X			
Lift and lower loose logs		X		X		X		X			
Parbuckle onto log, skids bundles		X		X	X	X	X	X	X		
Parbuckle onto log, skids loose logs	X	X		X	X	X	X	X	X		
Mobile loader over skids bundles		X			X	X	X	X	X	X	X
Mobile loader on gravel ramp, loose logs	X	X			X			X		X	
Helicopter drop			X			X			X		X
Sorting in water											
Loose logs		X			X		X	X			
Loose logs to make bundles		X			X			X			
Bundles			X		X						
Booming											
Bundle booms		X					X	X			
Flat rafts		X					X	X			
Bag booms		X					X	X			
Storage											
Bundle booms		X					X	X			
Flat rafts	X	X					X	X			
Bag booms	X	X					X	X			
Dry-land sort					X			X			
Barge loading and dumping											
Loose logs					X			X			
Bundles					X			X			
Transporting											
Bag booms	X	X		X	X	X	X	X	X		
Flat booms	X	X		X	X	X	X	X	X		

## PHYSICAL IMPACTS OF LOG HANDLING

### LOG DUMPING

Physical disturbances resulting from log dumping include substrate disturbances in areas where the logs contact the bottom, deposition of bark and wood debris and subsequent dispersion, deposition of other debris (for example, bundling bands) associated with the log handling, and loss of whole logs through sinkage. The magnitude and spatial extent of these disturbances differ greatly with the type of log dump, the depth of the water column, geomorphology and substrate composition at the dump site, log species handled, age of logs, the season and volume of the operation, and prevailing current and circulation patterns.

Consequently, the amount of substrate disturbance and debris accumulation differs among log-dump sites. Because log sorting, booming, and storage activities frequently occur in conjunction with dumping, distinguishing physical impacts resulting from different log-handling activities is difficult. Quantitative information describing some of these physical disturbances is limited.

### SUBSTRATE DISTURBANCES

No data are available on the effects of log dumping on bottom substrates, although the Ministry of Environment, British Columbia (1976), in a report dealing with Ladysmith Harbour, suggested that scouring could result when logs are dumped by free-fall

methods into shallow water. Because qualitative and quantitative data are lacking, we can only discuss substrate disturbances likely to result from log dumping.

The method of log dumping, water depth, and location of each site are the major factors influencing the degree of substrate compaction, scouring, or both. Of the basic methods of dumping, the least substrate disturbance would result from "lift and lower" and helicopter dumps, providing these activities did not occur in intertidal areas--particularly at low tide. On the other hand, parbuckle dumps and any form of skidding could cause more bottom disturbance, particularly in shallow water. Because log dumps remain in a single location while logging goes on in a particular area, substrate disturbances are likely to be localized except where more widespread accumulation of bark requires periodic dredging of larger areas. The greatest disturbance of substrate could result from barge dumping if logs touched the bottom in shallow water. Because barge dump sites must be located in areas with sufficient water depth to allow passage of large tugs, however, substrate disturbances from this activity are probably minimal.

The amounts of substrate disturbance resulting from dumping of bundled and loose logs are also likely to differ. The proportions of logs that are dumped loose or in bundles differ markedly by region. For all of coastal British Columbia, about 69 percent of the cut is bundled before dumping (FERIC 1980). In southeastern Alaska, over 99 percent of the timber cut is dumped as bundles (Faris and Vaughan 1985). Because bundled logs sink deeper before floating, a greater potential exists for contact with the bottom. As in all forms of dumping, however, this would cause substrate disturbances only if the dump site were in shallow water.

## BARK DEPOSITION AND DISPERSION

The deposition of bark and wood fiber at log dumps has been examined or discussed by several authors, including Conlan (1975, 1977); Ellis (1973); Ministry of Environment, British Columbia (1976); Pease (1974); Schaumburg and Walker (1973); and Schultz and Berg (1976). Four log dumps in coastal Alaska were examined during SCUBA surveys conducted by Ellis (1973); three of these dumps had been abandoned for 2 years or more. The divers observed bark and wood deposits at each site, with considerable variability in the depth of debris accumulation. One inactive dump site was characterized by only scattered deposits of decomposing wood and bark debris in depressions in the sea bottom in water up to 10 m deep. At another site, accumulations of debris were "several feet deep, black and foul, and obviously anaerobic." Debris accumulations were noted at water depths up to 23 m at two log dumps, and at one site the effects of dumping were evident for about 45 m on either side of the center of an abandoned dump (Ellis 1973), forming a pattern similar to a stream delta.

Studies of bark deposition in the Yaquina estuary in Oregon were conducted by Schaumburg and Walker (1973). Although the authors did not examine the spatial extent of debris accumulation, they reported that both mean particle size in the sediments and the proportion of organic solids were larger in areas of log handling. Three active and five abandoned log dumps in southeastern Alaska were examined in detail by Pease (1974). Benthic bark deposits were observed at all active and abandoned dump sites, but only scattered deposits were observed in log-storage areas. The depth of bark deposition was at least partially related to the period of activity of the dump site, the volume of logs handled, or both. One site that had been active for 10 years had bark deposits 60 to 90 cm deep, but only 5 to 8 cm of bark were found at a dump



that had been active for 1 year. Ellis (1973) found a similar correlation between the depth of bark deposition and period of use at other southeastern Alaska log-dump sites. Pease (1974) also noted that the area of substrate covered by bark differed between active and abandoned sites. At the oldest (7 to 10 years) active dumping sites, the bark-covered area extended a radius of at least 60 m from the point where log bundles were introduced into the water. At the sites that had been abandoned for 1 to 11 years, this radius was reduced to about 15 to 23 m. Scattered patches of white powder were observed on the bark at many of the dump sites; Pease suggested that this material was either magnesium or calcium sulfide. Bark deposits may trap silt particles transported from adjacent areas or introduced into the water column with the logs. Silt accumulations in bark deposits have been documented by Ellis (1973) and Pease (1974).

Log-transfer facilities at 32 sites in southeastern Alaska were studied by Schultz and Berg (1976). The bark coverage in front of each transfer facility was observed using SCUBA. The locations of bark accumulations were plotted on maps, and the areas of coverage were calculated. For 31 of the sites, the areas covered by bark ranged from 0 to 3.7 ha. Faris and Vaughan (1985) recalculated Schultz and Berg's (1976) data and obtained an average of about 0.8 ha of bark accumulation for the 31 observations, with a mode of 0.4 ha. At 13 sites, no measurable accumulation of bark or debris was found directly around the site. Presumably, the debris generated during transfer was transported (by gradient, currents, or tide) to deeper water, covered by sediment, or decayed. Faris and Vaughan concluded that conditions at each of the log-transfer locations were too variable to generalize about where and how much bark and debris would accumulate. More recently, Conlan (1977) examined the distribution of

bark debris around an active dump site and an abandoned dump site at Mill Bay, British Columbia. She reported that bark was deposited over an area of about 1 km<sup>2</sup> at each site. The deposits were thickest (>15 cm) close to the dumps, and thinned with increasing distance from the area. Considerable bark persisted at the site, which had been abandoned for 20 years, corroborating the observations of Ellis (1973) and Pease (1974) that dispersal of debris was slow from areas with poor water circulation. None of these studies measured currents directly, but inferred poor circulation based on the remaining deposits.

Other authors have discussed the fate of bark debris at dump sites and factors influencing the amount of deposition. Conlan (1975) suggested that decomposition of wood at dump sites would require 20 years or more; she cited studies conducted in a coastal lake in Oregon by Hansen and others (1971), which showed that bark debris was still evident after 30 to 40 years. Subsequent studies by Conlan (1977) confirmed the presence of bark deposits at a log dump at Mill Bay, British Columbia, that had been abandoned for 20 years.

Schaumburg (1973) studied the effects of log species handled and method of dumping on the amount of bark loss, and found that 17 percent of Douglas-fir bark was lost during dumping of loose logs, compared to about 6 percent for ponderosa pine (Pinus ponderosa Laws.), which has more tightly bound bark (table 2). Schaumburg (1973) also examined the effect of dumping method on bark loss by Douglas-fir, and reported average losses of 17 percent for slide-ramp (parbuckle) and 7 percent for A-frame hoist (lift and lower) methods.

Table 2--Incremental percentages of bark dislodged during logging, unloading, and raft transport (from Schaumburg 1973)

Species	Percent			
	During logging	During unloading	During raft transport	During unloading and transport
Douglas-fir	18.2	16.8	4.9	21.7
Ponderosa pine	5.7	--	--	6.2

-- = no data available.

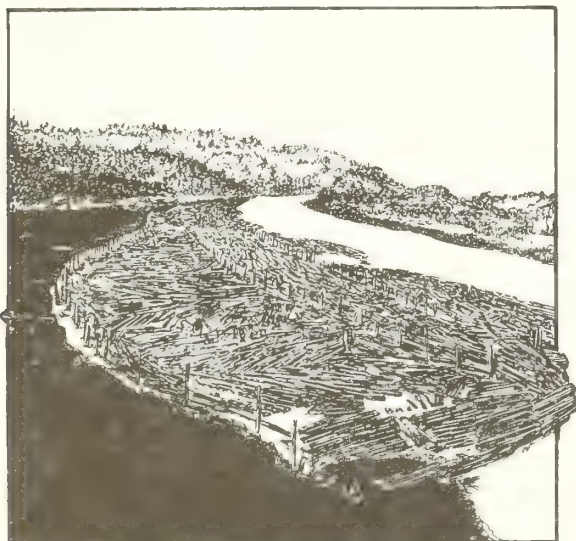
Sinking rates and dispersion of debris from log dumping are related to bark particle size. In experiments conducted on Douglas-fir bark, Schaumburg (1973) reported that smaller pieces of bark sank first, and that 10, 47, and 75 percent of the bark had sunk after 1, 30, and 60 days, respectively. Water currents near a dump site influence the pattern of bark deposition in two ways: while the bark remains afloat, it can be distributed over the water surface by currents and wind; once the bark sinks, its distribution may be subsequently altered by subsurface currents. Ellis (1970), in a study of three active dump sites in southeastern Alaska, found that water currents affect the extent of bark deposition. Although these dump sites had been used for 12 years, no bark and wood debris had accumulated, probably as a result of the strong currents in the area. Bundling of logs before dumping has been suggested to result in less bark loss (Conlan 1977; Hansen and others 1971; Ministry of Environment, British Columbia 1976), although bark loosened during preparation of the bundles and dumping may remain within the bundle and be deposited in areas where the bundles are broken.

In summary, bark deposition is a characteristic of most log-dumping areas that have been examined. Some methods of dumping and some species of logs result in greater bark losses. The limited data also suggest that the intensity of the operation and period of use of a dump site affect bark accumulation, and that deposits sometimes attain depths up to 90 cm (typically much less) and cover areas up to 1 km<sup>2</sup> around the dump site. Further study is needed, however, to provide information for planners on the mechanics of bark dispersal.

#### DEPOSITION OF OTHER DEBRIS AND LOG SINKAGE

Sunken logs and accumulations of inorganic debris have been observed at several log-dumping sites (Conlan 1975, Ellis 1973, Pease 1974); however, quantitative data on deposition of debris other than bark are lacking. Inorganic debris observed in waters adjacent to coastal log-dump sites in British Columbia and southeastern Alaska has included old cables, bundle straps, bottles, head gaskets from an engine, a cast-iron stove, an abandoned bulldozer, and other refuse. Wood shavings from boomstick boring have also been found at several sites (Pease 1974). The most prevalent type of debris is bundling straps, which are likely to decrease in the future because some operators now use wire cables that can be re-used.

Some logs have a specific gravity greater than 1.0 and sink immediately when dumped; others sink during storage once they become permeated with water. Waelti and McLeod (1971) reported that hemlock (*Tsuga heterophylla* (Raf.) Sarg.) logs were most susceptible to sinkage, and British Columbia Research Council (1964) showed that 1.1 percent of hemlock logs tested sank immediately. In this study, sinkage after 4, 11, and 28 weeks increased to 2.8, 4.1, and 9 percent, respectively, with the greater proportion of sinkers coming from hemlock harvested during the spring. Salvage operations are generally initiated where accumulation of sinkers hampers the movement of log dozers or other aspects of the log handling. The bundling of logs before watering, however, has greatly reduced log sinkage.



## LOG STORAGE

Log storage results in substrate disturbances in intertidal storage areas, leads to deposition of bark and wood debris, causes loss of logs through sinkage when logs are stored in flat rafts, reduces wave action, and decreases light penetration. Several of these physical impacts are also observed during log dumping, but log storage differs in either spatial extent or magnitude. The literature on the physical impacts of log storage is more

extensive than on log dumping, and includes studies conducted in British Columbia, Washington, Oregon, and southeastern Alaska.

### SUBSTRATE DISTURBANCES

Log storage can result in compaction or scouring of substrates when logs are stored in intertidal areas or shallow water. Ellis (1973) conducted SCUBA surveys under floating log rafts in Hanus Bay, Alaska, and was unable to distinguish any differences in the substrate character from those observed in a control area. Grounding of rafted logs in shallow intertidal areas, however, has been shown to result in significant disturbances to the substrate. For example, Pease (1974) reported that in an intertidal log-storage area, portions of the bottom had large depressions and were compacted to the consistency of sandstone by the action of log bundles grounding at low tide. Similar observations have been made in the estuaries of the Squamish River, Washington (Levings and McDaniel 1976); Nanaimo River, British Columbia (Sibert and Harpham 1979); and Snohomish River, Washington (Smith 1977). In the first study, sediments on beaches were disturbed by abrasion and scouring from resting logs at low tide, disruption from towing the logs on or off the beach, or both. Sibert and Harpham (1979) examined the substrate under an intertidal log-storage area in the Nanaimo River estuary where both flat raft and bundle booms were present. The bottom was characterized by grooves (up to 15 cm deep), parallel to the stored logs. These sediments were also compacted and the redox-potential discontinuity layer was located closer to the sediment-water interface than in areas unaffected by log storage. Sibert and Harpham (1979) suggested this discontinuity layer resulted from reduced circulation of interstitial water. They also noted that movement of bundle booms by tugs contributed to substrate scouring and subsequent release of hydrogen sulfide. Smith (1977) also noted the presence of troughs and ridges caused by grounding of logs in the Snohomish River estuary, Washington.



The potential for disturbance of intertidal substrate during log storage is highest with bundle booms because of their greater draft, although substrate disturbances resulting from log sinkage are simultaneously minimized by bundling of logs. Some operators, however, locate storage facilities in sheltered areas with sufficient water depth to prevent grounding of bundles or flat rafts at all times.

#### BARK DEPOSITION AND DISPERSION

The abundance and distribution of bark and woody debris under log-storage areas has been intensively investigated. Most studies have shown that bark accumulation in areas used for log storage is considerably less than in areas used for log dumping, although water circulation patterns also influence the degree of bark accumulation (Pease 1974, Sibert and Harpham 1979). For example, Sibert and Harpham (1979) found bark and other debris in pits and depressions under log booms, but the accumulations were localized and relatively small. Sediment particle size was smaller and organic content was higher in sediment samples collected under log booms than in control samples. These trends were previously observed under logs stored in the Yaquina River estuary on the central Oregon coast (Schaumburg and Walker 1973).

#### OTHER PHYSICAL DISTURBANCES

Other impacts include log loss from sinkage, reduction of wave action, decreased light penetration when suspended wood fibers are present in the water column, and shading of the substrate. Loss of logs from sinkage does not generally occur during storage when bundles are used (Conlan 1975, Pease 1974). In areas of flat-raft storage, log sinkage can subsequently affect benthic invertebrate communities, increase available habitat for shipworms (*Bankia setacea* Tyron), and result in the proliferation of fungal and bacterial decomposers (Conlan 1975).

Conlan (1975) suggested that log rafts in storage may reduce wave action and therefore increase rates of silt and log-debris sedimentation. Although quantitative data to assess this area of impact are limited, observations by divers under log rafts stored in the Nanaimo River estuary indicate that logs stored intertidally act as silt traps for materials transported by the Nanaimo River.

Conlan (1975) suggested that log dumping and storage decrease light penetration as a result of scattering by suspended wood fibers and shading. Although this decrease probably occurs, neither effects of suspended debris and rafted logs on light intensity nor the spectral composition of available light have been measured.

### LOG SORTING AND TRANSPORT

No quantitative data are available that distinguish the physical and chemical impacts of water sorting and transport of logs from effects of log dumping and storage. Some impacts can nevertheless be suggested from study-team observations. Because water sorting with log dozers (British Columbia term) or boom boats (U.S. term) involves repeated and often vigorous contact with logs, considerable loosening and deposition of bark can be expected. Log dozers also create turbulence in the water column from propeller wash, which could disturb the substrate in shallow sorting grounds and contribute to release of hydrogen sulfide in decomposing wood and bark debris, as well as scatter the bark. Log sinkage in sorting grounds undoubtedly occurs, particularly when bundles containing hemlock are broken down for further sorting.

The only potential sources of physical impact during log transport outside booming and storage grounds are log losses either from sinkage from flat-raft booms or from loss or breakage of entire booms during adverse weather or rough seas. When salvage operations are undertaken to recover lost logs, physical impacts to shoreline areas are relatively short term and minimal.

Movement of logs by tugs in shallow estuarine areas can result in both debris accumulation and substrate scouring. For example, tug propeller wash during transport of flat rafts and bundle booms in the Nanaimo River estuary has resulted in substrate scouring to depths ranging from 0.5 to 1.5 m, although these scoured areas gradually fill in with sediments transported by the river (Fish Habitat and Log Management Task Force 1980). Grounding of bundle booms during towing in this estuary contributes to additional scouring, and breakage of bands, cables, or both on impact with the bottom is responsible for accumulation of these strapping materials on the substrate.

## DEBRIS ACCUMULATION

The debris resulting from log handling also includes lost logs that remain afloat and subsequently become stranded along shorelines, and deadheads or low floaters that may also accumulate on beaches or eventually sink.

Waelti and McLeod (1971) estimated that 680 000 m<sup>3</sup> of logs were lost annually in the coastal Vancouver Forest Region. The volume of natural debris (as well as debris other than logs from log handling) has not been well documented. On some beaches, up to 90 percent of the debris has cut ends, indicating they originate from logging or construction. In southeastern Alaska, most woody debris on the beaches is natural (Beil 1974, Forest Engineering Incorporated 1982). Council of Forest Industries (1974, 1980) estimated that gross log losses (including sinkage, but excluding recoveries by the British Columbia Log Spill Recovery Association) amounted to 827 000 m<sup>3</sup>. Roughly 40 percent of these losses were eventually recovered by log-salvage permittees and others, another 35 percent (chiefly hemlock) sank, and the remaining 25 percent were lost to beaches or the open sea.

Evans (1977) noted that the greatest proportion (about 70 percent) of wood debris in Georgia Strait resulted from log-handling losses on the inside waters of the British Columbia south coast (table 3). Hemlock (particularly smaller logs) was always the main species lost. Recent moves by some companies to increase dry-land sorting, water bundling, or both, have greatly reduced flat rafting and associated log losses.

Council of Forest Industries (1974) estimated log losses by species and log size for each of four basic handling methods (table 4). The accumulation of these materials on beaches has been discussed by Waelti and MacLeod (1971). These authors reported that gently sloping beaches accumulate the most debris, and rocky, steep shorelines trap relatively few logs. Waelti and MacLeod (1971) suggested that beach debris can be classified into three age groups: transient material lying below average high tide, which may be naturally removed within one change of tide; material lying above average high tide ("new drift"), which is subject to dislocation and drift to another area during extreme tides; and "old drift" deposited permanently above and behind high tide by extreme tides and winds. They emphasized that the second category of material comprises the bulk of the beach wood, and the third category is generally old and at least partially decomposed.

Table 3--Sources of logs and debris and estimated volume in Georgia Strait (from Evans 1977)

Source	Volume of logs and debris
	<u>Cubic meters</u>
Log transport and storage	297 000
Mills on Burrard Inlet and the Fraser River	42 000 to 85 000
Howe Sound sorting	6 000 to 11 000

Table 4--Estimated log losses for each of 4 basic handling methods (from Council of Forest Industries 1974)

Log-handling methods	Portion of production in 1974	Losses
	<u>Percent</u>	
Dry-land sort and bundles, direct trucking to mills, or both	20	0.33
Water-bundled before towing to mills	23	1.7
Dump, sort, and flat-raft transport to mills	35	3.2
Barging of loose logs, dumping, and flat-raft transport to mills	22	6.1

## CHEMICAL IMPACTS OF LOG HANDLING

The major chemical impacts of log handling are increased biochemical oxygen demand (BOD), hydrogen sulfide and ammonia production during the decomposition of bark and woody debris, and the release of soluble organic compounds (leachates) from logs. When present in sufficient quantities, leachates also exert an oxygen demand on adjacent waters and impart a yellow to brown color to the water. The literature describing the chemical impacts of log handling is extensive.

## DECOMPOSITION OF BARK AND LOG DEBRIS

The decomposition of bark and wood debris in water is comprised of two phases. The first phase is a relatively rapid process mediated by heterotrophic bacteria; the second phase is slower, requiring lignin-decomposing fungi, which are common in terrestrial ecosystems but not in marine environments. Decomposition in this slower phase, however, is often augmented by boring organisms--that is, Bankia setacea and Limnoria lignorum--which increase fungal access to the interior of the wood.

Decomposing bark and wood in the water column and on the substrate both create a biochemical oxygen demand. The oxygen demand of wood debris suspended in the water column is insignificant, however, if currents are greater than 0.01 m/sec (Pease 1974), which is generally true in surface waters under the influence of tidal currents. FERIC (1980) reported that tidal currents in 47.3 percent of the log-handling lease areas in coastal British Columbia were negligible; thus, BOD in the water column may be higher than normal in some areas. BOD becomes a measurable and significant process at the water/sediment interface, where circulation of oxygenated interstitial water may be reduced and bark deposits may accumulate.



## INCREASED BIOCHEMICAL OXYGEN DEMAND

The oxygen uptake of benthic bark deposits has been measured by McKeown and others (1968), Pease (1974), and Schaumburg (1973). These authors reported oxygen demands from 0.2 to 4.4 g O/m<sup>2</sup> per day, depending on ambient conditions. Schaumburg (1973) found that the oxygen demand of bark deposits in Oregon coastal waters increased with the concentration of organic solids in the deposits and increased surface area of the log debris. He also indicated that oxygen demand was not related to the depth of bark deposits. Ponce (1974) also demonstrated a relation between oxygen demand and distribution of log-debris particle size and surface area. McKeown and others (1968) indicated that mixing or water turbulence above the substrate increases the oxygen demand of benthic bark deposits by accelerating decomposition. Uptake ranged from 0.2 to 0.8 g O/m<sup>2</sup> per day under stagnant conditions, but water movement above the deposits increased the demand to 2.7 g O/m<sup>2</sup> per day. Gentle scouring of the benthic bark deposits further raised the oxygen demand to 4.4 g O/m<sup>2</sup> per day.

## INCREASED HYDROGEN SULFIDE CONCENTRATIONS

With the exception of beaches exposed to a strong surf, marine sediments are generally anaerobic and chemically reducing beneath a relatively thin oxidized layer (Fenchel and Riedl 1970). Consequently, degradation of wood and bark debris in estuarine and marine sediments is primarily through sulfate reduction. This bacterially mediated process results in production of hydrogen sulfide, various organic compounds, and carbon monoxide. Hydrogen sulfide reacts with soluble iron in interstitial waters to form ferrous sulfide (FeS), although phosphate also competes with sulfides for available iron in interstitial waters. When the available iron is used or its rate of use exceeds that supplied to or regenerated within the sediments, additional free sulfides exist within the interstitial waters, and pyrite--which is formed from

ferrous sulfide--becomes an irreversible sink for available iron. The formation of pyrite decreases the total sulfide capacity and increases the probability of free sulfide formation (Bella 1975). The tendency for the leached extracts from bark and debris deposits to exhaust the iron in surface sediments is evident from the high concentrations of free hydrogen sulfide present in benthic wood deposits (Pease 1974).

Within undisturbed sediments, the FeS content increases as available organics are decomposed, and as long as the FeS content does not approach the total sulfide capacity, free sulfide will not be formed. Physical disturbance or flushing of the sediment with aerobic waters will oxidize the FeS and release the sulfide. Then, the sediments undergo a series of cycles in which the FeS increases during the periods of physical stability and rapidly decreases during sediment disturbance. Such disturbances have been observed in the Campbell River and Nanaimo River estuaries as a result of tug-boat propeller wash during log handling (Sibert and Harpham 1979, Vigers and Hoos 1977). During both of these studies, hydrogen sulfide concentrations were not measured, but were detectable by smell. Bubbling of hydrogen sulfide from benthic bark deposits has also been documented at coastal British Columbia log dumps.

If bark and debris in log dumping, sorting, and storage areas represents a biodegradable organic source that exceeds the available iron capacity, then the conversion of all available iron to iron pyrite assures the continued production of free sulfide. Conlan (1975), however, cited only one instance when resultant hydrogen sulfide concentrations reached toxic concentrations, which occurred when organic matter was buried under beach gravel (Hansen and others 1971). Other laboratory studies with fish have shown that acute lethal concentrations of hydrogen sulfide have ranged from 0.8 to 7.0 mg/liter depending on test species and pH (U.S.

Environmental Protection Agency 1971). No quantitative information is available, however, to indicate the increase in hydrogen sulfide production from log debris is above that normally associated with decomposition in marine sediments.

## WOOD LEACHATES

Significant quantities of soluble organic compounds are released by logs stored in water as well as by submerged bark deposits (Conlan 1975). The character of these leachates depends on the tree species, but it generally includes tannins, resins, oils, fats, terpenes, flavanoids, quinones, carbohydrates, glycosides, and alkaloids (Wise 1959). The tannin, flavanoid, resin, and quinone components are primarily responsible for the yellow to brown color associated with leachates, and each of these components contributes differently to oxygen demand (Schaumburg 1973). Leaching is faster in salt water than in fresh water, and the rate of leaching decreases as the quantity of soluble organics in surrounding waters increases. In flowing water, the leaching process is nearly constant for at least 30 days (Hansen and others 1971).

Schaumburg (1973) reported that 60 to 80 percent of the solids leached from wood are volatile, although the rate of leaching varies with the flushing rate, species and age of wood, time the wood or bark has been in the water, and temperature (Atkinson 1971, Gove and Gellman 1971). Gove and Gellman (1971) also noted that the greatest proportion of leachate was released from the cut ends of logs and the bark. Although in-place leaching rates may be quite different, Pease (1974) ranked tree species according to their leaching rates (from highest to lowest, as follows: western redcedar (Thuja plicata Donn ex D. Don), Alaska-cedar (Chamaecyparis nootkatensis (D. Don) Spach), western hemlock (Tsuga heterophylla (Raf.) Sarg.), and Sitka spruce (Picea sitchensis (Bong.) Carr.).



Conlan (1975) has suggested that the yellow to brown color imparted to surrounding waters by leachates could affect light penetration and thus algal growth. The increased chemical oxygen demand (COD) resulting from log leachates has been examined by Schaumburg (1973), who reported a decrease in the COD of Douglas-fir leachate from 0.46 to 0.07 g/m<sup>2</sup> per day after 25 to 30 days.

A major concern about leachates is their potential toxicity to marine and freshwater flora and fauna. Various authors, including Conlan (1975) and Pease (1974), have noted that the toxicity of leachates in seawater is negligible because of the tendency of lignin substances to precipitate in complex with chloride ions. Therefore, the greatest potential for adverse effects of leachates to biological resources would be near freshwater log-handling sites, although benthic microflora and microfauna may be adversely affected by precipitates formed in marine waters. At the same time, however, some of the organic constituents of leachates, such as glucose, may be beneficial to some species.



# SUMMARY OF PHYSICAL AND CHEMICAL IMPACTS

The physical and chemical impacts of log handling depend primarily on the location and areal extent of the operation, the volume and species of logs handled, the activities occurring at the site, and particularly the local current patterns and intensity. The impacts of all phases of log handling are greater when activities affect intertidal areas. The most significant effect of log dumping is the accumulation of bark and wood debris on nearby bottom sediments. This form of physical impact is most pronounced with free-fall (nonmechanically controlled) dumps in areas of poor circulation. Other significant impacts of some log-dumping operations include substrate scouring or compaction and loss of logs through sinkage. Secondary or subsequent impacts are chemical and associated with release of hydrogen sulfide, increased BOD during decomposition of accumulated bark and wood, and the release of wood leachates, which also exert COD.

Log storage results in many of the same physical and chemical impacts as log dumping, as well as additional effects related to shading of the substrate in shallow water, reduced wave action, and a potentially greater opportunity for release of leachates when logs are stored for extended periods. Less bark and wood debris deposition is assumed to result from log storage than from dumping, but substrate compaction and scouring can be greater when logs are stored in intertidal areas. Log sinkage in storage grounds is minimized through use of bundle booms, although this practice may intensify impacts related to log grounding in intertidal areas. Silt also sometimes accumulates in estuarine log-storage grounds.

The most significant impact of log sorting is the release of additional bark and wood debris, although log dozers working in shallow waters can also contribute to substrate disturbance. Log transport only results in significant physical impacts when activities take place in shallow estuarine areas. Then, extensive substrate scouring can result from the propeller wash of tugs.

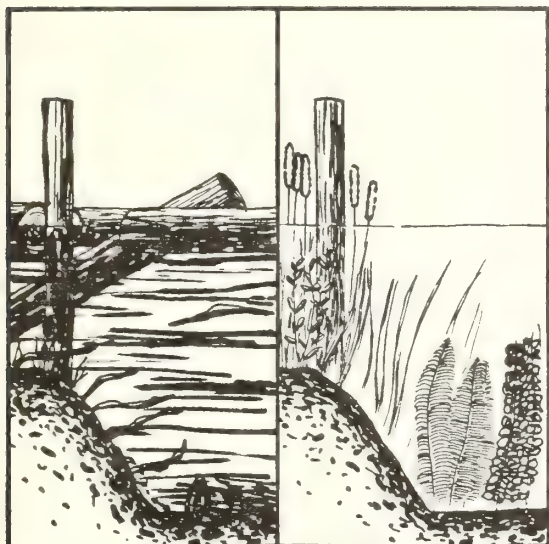
## DATA DEFICIENCIES

Deficiencies in data on the physical and chemical effects of log handling are only important as they limit subsequent assessment of impacts to biological resources. Specific deficiencies are:

- Data describing the extent of substrate disturbance resulting from various methods of log dumping, particularly in shallow waters.
- Quantitative information on differences in substrate disturbance and bark deposition associated with dumping and storage of loose compared with bundled logs.
- Species-specific information describing rates of bark decomposition and dispersal under different flushing conditions.
- Measurements of light intensity and turbidity at various depths below stored log booms and at various distances from log-dump sites.
- In-place measurements of biochemical oxygen demand, chemical oxygen demand, hydrogen sulfide concentration, and leachate concentration in interstitial waters affected by wood and bark debris, as well as at various depths in the water column in poorly flushed areas.
- Bark loss between various entry systems.



- Bark loss between entry, booming, and storage operations.
- Threshold water-current rates that ensure bark dispersal.
- Relations between bark loss and species and age of logs.



## IMPACTS OF LOG HANDLING ON PLANT COMMUNITIES

Impacts on plant communities may result from scouring of both hard and soft substrates, compaction of soft substrates, shading and other alterations in the light environment, deposition of bark and wood debris, and toxic or sublethal effects associated with increased oxygen demand and release of log leachates (Bell and Kallman 1976b, Conlan 1975). Although several authors have discussed the impacts of various phases of log handling on plants, no quantitative data and only a limited amount of observational information are available describing these impacts. Despite this apparent lack of published information, damage to emergent vegetation in particular is clearly evident in many coastal areas used for log handling (Duval and others 1980).

## SUBSTRATE DISTURBANCES

Substrate disturbances may occur during log dumping, sorting, transport, and storage, but generally only when these activities take place in intertidal waters. Physical disturbances to substrates may also result when lost logs become stranded along shorelines and on beaches. Because quantitative data describing the impacts of these physical disturbances on plant communities are lacking, this section discusses qualitative observations of various authors, as well as potential impacts on plants based on known types of substrate disturbance resulting from log handling.

Several authors have observed or suggested impacts on plant communities resulting from the scouring or compaction of substrates by rafted logs. Bell and Kallman (1976c) reported that logs stored in the Nanaimo River estuary had adverse impacts on the eelgrass (*Zostera marina* L.) meadows as well as on the macrobenthic and microbenthic algae, but did not provide details regarding the type and extent of this damage. The earlier reports of Narver (1972) and Trethaway (1974) suggested that either propeller wash or dragged logs had resulted in gouging of the substrate in and near the larger eelgrass beds in the Nanaimo estuary. Naiman and Sibert (1979) reported that scouring of sediments in this estuary had severely limited benthic primary production, but provided no quantitative data to support their view. Other authors have suggested that log storage in the Cowichan, Chemainus, Campbell, Squamish, and Kitimat River estuaries has resulted in some degree of substrate disturbance that has subsequently affected plant communities (Bell and Kallman 1976a, 1976b; E.V.S. Consultants Ltd. and F.L.C. Reed and Associates 1978; Levings and McDaniel 1976).

## ACCUMULATION OF BARK AND WOOD DEBRIS

Plant communities on both rocky and soft substrates may be damaged by log handling. Abrasion-related damage on rock substrates has been observed at Bath Island, Georgia Strait, where loose logs removed all algal vegetation from flat table rocks but generally not from vertical faces or crevices in the rock (Duval and others 1980). In an attempt to simulate and assess the long-term effects of log abrasion on an algal community, DeWreede (cited in Duval and others 1980) removed Lithothrix sp., a coralline alga, from a portion of intertidal substrate, and found that the area was subsequently recolonized by a filamentous red alga, Rhodomela larix Agardh. In a similar study, Dayton (1971) reported that log abrasion removed intertidal algae from several sites in the San Juan Islands, Washington, and this subsequently affected the species composition of intertidal invertebrate communities.

The potential for plant removal resulting from substrate disturbance depends on the morphology and growth patterns of different algal groups. Perennial plants that can regenerate from the holdfast have a better chance of survival after disturbance than those that require a portion of blade or frond for regeneration. Annuals will not reestablish in a given year if they are removed by substrate compaction or scouring before their reproductive period.

Eelgrass is the most common plant on soft, particularly muddy, substrates in coastal British Columbia waters (Scagel 1971). Several red algae, filamentous greens, and dwarf browns are also adapted to mud substrates in some areas (Ranwell 1972). Abrasion of eelgrass and emergent vascular plants by logs in these soft substrates would likely result in either fragmentation or uprooting of the plants. Although quantitative data are lacking, extensive damage to emergent vegetation fringing intertidal log-storage areas has been noted by several authors. Recovery of eelgrass in areas previously used for log handling was indicated during a study by Pease (1974), and emergent vegetation may similarly recolonize disturbed habitats.

Data describing the effects of bark and wood-debris accumulation on plant communities are limited. The effects of log handling on flora of the Campbell River estuary were discussed in a report by E.V.S. Consultants Ltd. and F.L.C. Reed and Associates (1978). Intertidal areas with heavy debris accumulation were characterized by decreased species diversity of benthic flora and oxygen depletion within the sediments, although no adverse impacts of log handling were observed in subtidal regions. Duval and others (1980) summarized several reports that also suggested that bark-debris accumulation may result in decreased abundance of benthic microalgae and macroalgae, but quantitative supportive data are lacking. Pease (1974) examined plant communities (algae and eelgrass) at several abandoned and active log-dumping or storage sites in southeastern Alaska. Plants were sparse at two dump sites that had been in operation for 10 years, but at two other sites in use for only 1 year, green algae (Chlorophyta) and eelgrass were described as "abundant." Pease (1974) found no consistent trends in rates of algal or eelgrass recolonization at log-storage or dumping sites as a function of the period of abandonment.

Accumulation of bark and wood debris could result in direct and indirect, as well as positive or negative, impacts to different types of plant populations, depending on the depth of accumulation and concomitant chemical changes in the environment. The results of studies by Pease (1974) suggest that both microalgae and eelgrass are adversely affected in areas of heavy bark accumulation and poor tidal flushing. On the other hand, scattered and light accumulations of debris could benefit some macroalgae (kelps) by providing more suitable substrate. Some constituent, such as glucose, in log leachates may also stimulate the growth of plant species capable of heterotrophic uptake. This uptake is not likely to be important with benthic microalgae adapted to low light and relying primarily on heterotrophic production.



## CHANGES IN THE LIGHT ENVIRONMENT

Many reports that discussed the impacts of log handling on marine plant communities suggested that shading results from log storage, and increased water turbidity is associated with log dumping and sorting. Although these types of disturbances undoubtedly occur in the light environment, the light intensity, spectral composition, and water turbidity near log-handling sites have not been measured, and adverse effects on plants of these changes have largely been inferred. Similarly, rates of primary production and the standing stock of plant communities affected by various aspects of log handling have not been determined.

The effects of changes in the light environment would probably vary with species and seasonal differences in their light requirements and at present can only be assumed. Greatest impacts would likely occur from shading of plants under rafted logs. Decreased light intensity may reduce rates of primary production and growth, and eventually lead to the loss of benthic microalgae and macrophytes from these areas. On the other hand, free-floating plants (phytoplankton) would not be significantly affected by shading because these organisms would not remain in environments with reduced light.

Particulate matter, such as silt and fine bark debris, may enter the water column as a result of log handling and contribute to increased turbidity. Because no studies have been conducted on turbidity from log handling, we can only assume the effects. When present in sufficient quantities, particulate matter could reduce light intensities and cause changes in the spectral composition of available light because of the tendency for suspended particles to differentially scatter short wavelength (<500 nm) radiation. Both of these changes in the light environment could temporarily affect pelagic or benthic plant communities, either

through the effects of light intensity on rates of photosynthesis or by the role of light quality on the differential growth of different species. Impacts of these types are probably extremely localized, however, and of minor concern in log handling in coastal marine environments.

## CHEMICAL EFFECTS

To date, the chemical effects of log handling on plant communities have not been examined, although both positive and negative impacts are possible. Chemical changes associated with log handling can include increased BOD and hydrogen sulfide production during the decomposition of wood and bark debris deposits, and the release of log leachates with subsequent physical-chemical effects (increased COD, coloration of water, increased concentrations of dissolved organic compounds). Chemical impacts on plants would probably be restricted to benthic species in the immediate vicinity of heavy accumulations of bark debris and to both pelagic and benthic species near recently watered logs still releasing leachates. Adverse impacts could include sublethal and toxic effects resulting from the presence of log leachates or hydrogen sulfide associated with decomposing bark and wood debris. Decreased autotrophic production, because of the light-attenuating effects of highly colored leachates, could also result. As indicated earlier, log leachates could also have positive influences on plants by increasing the availability of compounds important in the heterotrophic production pathways of some algal species.

## SUMMARY OF IMPACTS

Assessment of the impacts of log handling on plant communities is severely limited by lack of quantitative data and the observational nature of existing information. As summarized in table 5, both positive and negative effects on plants could result from physical and chemical factors associated with log dumping, sorting, storage, and transport in



Table 5--Summary of log-handling impacts on plant communities

Log-handling effect	Major source of effect		Positive impacts	Mode of action	Negative impacts	Mode of action
Compaction or scouring of soft substrates	Log dumping in shallow areas and intertidal log storage; propeller wash in shallow areas		None	--	Physical damage and uprooting of eelgrass and emergent vegetation; potential decreased primary production by benthic microalgae	Direct
Scouring or abrasion of hard substrates	Log dumping in shallow areas; stranding of lost logs in intertidal environments		None	--	Physical damage to intertidal algae	Direct
Accumulation of wood and bark debris	Log dumping and sorting; minimal contribution by log storage		Increased habitat for some macrophytes in areas with scattered debris; use of dissolved organic compounds in leachates by heterotrophic forms	Direct and indirect	Decreased species diversity and abundance of benthic microalgae and macrophytes. Potential indirect impacts from chemical changes in bottom waters (H <sub>2</sub> S and log leachates)	Direct
Changes in the light environment (quality and intensity)	Log dumping related to increases in water turbidity; shading by rafted logs; presence of highly colored leachates		None	--	Decreased primary production by autotrophic species; potential changes in species composition in benthic forms under rafted logs	Indirect
Time considerations						
	Short-term (<10 yr)	Long-term (>10 yr)	Space considerations	Probable recovery potential (years)	Degree of impacts	Factors influencing degree of impacts
Compaction or scouring of soft substrates	X	None	Insignificant area affected by log dumping; up to moderate coverage of some estuaries	5	Insignificant to minor	Presence of extensive eelgrass meadows would increase potential for impacts; intertidal log storage in estuaries would also increase impacts
Scouring or abrasion of hard substrates	X	None	Insignificant area of impact in regional terms	5	Insignificant	
Accumulation of wood and bark debris	Chemical-related impacts	In areas of heavy debris accumulation and poor tidal flushing	Insignificant to moderate; depending on tidal flushing and log-handling techniques	5-10	Insignificant to moderate	Impact assessment hampered by data deficiencies; impacts would be greatest in estuarine areas where plant communities provide habitat or food for invertebrates, fish, birds
Changes in the light environment (quality and intensity)	Turbidity and coloration effects	Shading in long-term log-storage areas	Insignificant area of impact	5 5	Insignificant to minor	Shading by extensive log storage in estuaries would increase potential for light-related impacts; also depends on time of year

-- = not applicable

marine waters. Although existing information is not sufficient to define degree of impact accurately, these effects cannot be considered more than minor or moderate in a regional sense. Note that site-specific damage to some plant species, especially eelgrass and emergent vegetation, can be moderate to major. Impacts of log handling on plant communities would be intensified in those coastal areas of British Columbia and southeastern Alaska where emergent vegetation is not abundant, but nevertheless provides important or critical habitat for aquatic birds and mammals associated with shorelines.

Other potential impacts are on estuarine eelgrass and emergent plant communities affected by shading and substrate disturbances that result from storage of logs in shallow waters. A study of log-handling leases in coastal British Columbia waters by FERIC (1980) indicated that 27.2 percent of water leases (2400 ha) were less than 3 m deep, and the potential for damage to nearshore plant communities was highest in these areas. Primary production by benthic microalgae could also be reduced in such areas, and this could subsequently affect secondary production by invertebrate grazers.

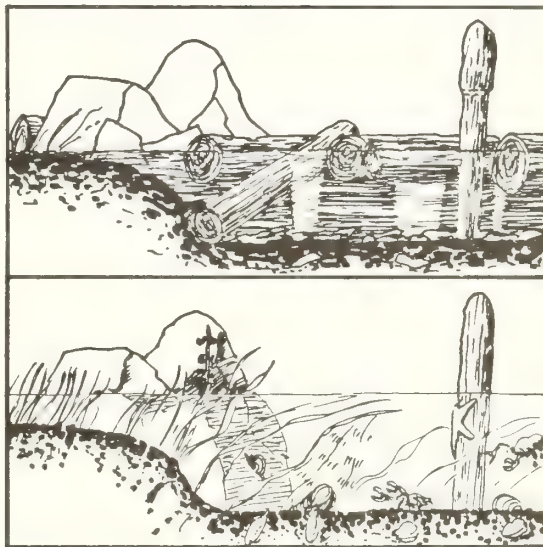
## DATA DEFICIENCIES

Almost no data are available describing the impacts of log handling on plant communities, with the majority of the available information being either qualitative observations or speculation based on alleged physical-chemical effects. Given the trophic position of plant communities and the fact that production by primary and secondary consumers is closely tied to primary producers, many of these data deficiencies should be subjects of future investigation. Specific areas where information is needed for impact assessment include:

- Quantitative data describing the effects of substrate disturbances on eelgrass and emergent macrophyte beds in estuaries, as well as information documenting rates of

recovery after log-handling sites are abandoned, and mechanical bark removal from log-handling sites.

- The effect of bark-debris accumulation on benthic microalgae, including potential sublethal and toxic effects of hydrogen sulfide and log leachates.
- The potential for increased heterotrophic production by plant species affected by certain dissolved organic constituents in log leachates.
- Information describing alteration in the light environment and the effects of potential changes in light quality and intensity on rates of primary production, particularly under rafted logs in estuaries.



## IMPACTS OF LOG HANDLING ON BENTHIC AND INTERTIDAL INVERTEBRATES

The effects of log handling on benthic invertebrates in coastal environments have been described in qualitative studies at log-dumping and storage sites in southeastern Alaska and Howe Sound, British Columbia (Ellis 1973, McDaniel 1973). Quantitative

studies that examined the abundance and diversity of benthic organisms relative to log handling have also been conducted in southeastern Alaska (Pease 1974), British Columbia (Conlan 1977, Conlan and Ellis 1979, Sibert and Harpham 1979), and Washington and Oregon (Schaumburg 1973, Smith 1977, Zegers 1978); reviews of available literature describing impacts of log handling on invertebrates were provided by Conlan (1975, 1977), Hansen and others (1971), and Smith (1977).

These studies suggest that the effects of log handling range from major changes in the physical environment--which results in decreased abundance of benthic invertebrates, changes in community structure, or both--to localized positive influences on some invertebrates associated with bark and debris habitat. These studies also indicate that log-handling effects on benthic and intertidal invertebrates are related to: direct physical disturbances to the sea bottom (scouring, filling, and compaction of the sediment) at log dumps and intertidal storage sites; the accumulation of bark and other debris from dumping, sorting, and storage activities; or both. The spatial extent and degree of impact are directly related to the flushing characteristics of waters near the log-handling site, the methods of handling logs, the intensity of use in each area, the location of these areas, and the ecological and commercial importance of affected species.

## IMPACTS OF PHYSICAL DISTURBANCE

At log-dump sites, impacts associated strictly with scouring and compaction of the bottom sediments have not been documented. This is largely because at shallow-water dump sites, where bottom disturbance is likely (such as dumps using parbuckle, slide-ramp systems, or both), large amounts of bark and wood debris frequently accumulate, so separating the effects of these two forms of disturbance is difficult. Fauna are expected to be depleted in the relatively small areas where logs come

in contact with the bottom during dumping. Fauna that could be affected include clams, crabs, oysters, sedentary polychaetes, and any other animals that depend on macroscopic plants--such as eelgrass--that may be eliminated during dumping activities in shallow water. Because the areas directly affected by physical contact with logs at dump sites are usually small relative to the available habitat in adjacent areas (about 200 ha in coastal British Columbia, FERIC 1980), the total effect of physical substrate disturbances at dump sites to coastal benthic invertebrate communities is minor.

Physical disturbance to the substrates at log-storage sites has only been documented in intertidal storage areas where log booms or bundles "ground" during low tide. In these areas, changes in abundance of invertebrates, species composition of invertebrate communities, or both have been significant and measurable. Repeated grounding of log booms during low tides causes sediment compaction which either prevents substrate use by macro-infaunal species (predominantly suspension feeders, such as clams) and results in a shift to predominantly infaunal detritus feeders or occasional elimination of the benthic infauna by crushing (Pease 1974, Sibert and Harpham 1979, Smith 1977, Zegers 1978). For example, at Buckley Bay on Vancouver Island, Conlan and Ellis (1979) reported that populations of clams and oysters were reduced in areas of intertidal log storage as a result of sediment compaction. Studies in southeastern Alaska by Pease (1974) and in Washington by Smith (1977) also indicate significant decreases in the abundance of benthic epifauna and infauna at intertidal storage sites where sediment compaction had occurred over prolonged periods. Zegers (1978) found the total number of benthic organisms on grounded areas of Coos Bay, Oregon, to have been reduced between 88 and 95 percent. Direct physical disturbance to benthic infauna



and plants providing habitat for epibenthic organisms may also result from the propeller wash of log dozers and tugs operating in shallow waters. Impacts of this type have included windrowing of oysters and washout of clams (Duval and others 1980).

On the other hand, Sibert and Harpham (1979) observed no adverse effects of intertidal storage on benthic epifauna in the Nanaimo River estuary. They found a greater density of epibenthic harpacticoid copepods (an important prey species of some species of juvenile salmon) under intertidal log booms, but reported no consistent trends in harpacticoid densities relative to the intertidal storage of flat rafts or bundles. Although measurements of infaunal abundance were not undertaken during this study, Sibert and Harpham (1979) did suggest that infaunal habitat was probably reduced by sediment compaction.

Levy and others (1982) used basket traps and stream samples to compare the relative abundance of epibenthic invertebrates in the Point Grey log-storage area and the Musqueam Marsh in the north arm of the Fraser River estuary. They found the mysid Neomysis mercedis Holmes was more abundant in the log-storage area, the isopod Gnorimosphaeroma oregonensis Dana was more abundant in the marsh, and the amphipods Eogammarus confervicolus Birstein and Corophium sp. were similar in abundance in the two areas. They conducted three large-scale invertebrate-distribution studies and found that in two of the studies E. confervicolus was uniformly distributed throughout the two study areas. Corophium sp. were most numerous along the marsh-log storage boundary, and relatively high numbers of G. oregonensis were found throughout the Musqueam Marsh. Levy and others (1982) believe that the hard-sediment consistency in the log-storage area caused by repeated log groundings may have reduced the abundance of Corophium sp. They

also believe the low salinity of the Musqueam Marsh and the intermediate salinity of the Point Grey log-storage area may have caused mortality of Corophium sp. and E. confervicolus, respectively.

Another source of physical disturbance to intertidal invertebrates is the accumulation of lost logs along shorelines. Data describing the effects of this disturbance to intertidal fauna are limited (Dayton 1971), although both positive and negative influences are likely. In rocky areas, stranded logs may crush organisms, particularly those logs that are repeatedly moved to different areas on subsequent tidal cycles. On gradually sloping shorelines where most log accumulation occurs (Waelti and MacLeod 1971), substrate compaction may affect infauna in the same way as log grounding affects it in intertidal storage areas. On the other hand, some intertidal organisms may benefit from log-debris accumulation in the intertidal zone. For example, the amphipod Anisogammarus confervicolus Stimpson and the isopod Exosphaeroma oregonensis Dana are extremely abundant within and adjacent to decomposing logs and wood debris in the mud flats of the Squamish River estuary (Levings and McDaniel 1976), although deeper areas in the substrate characterized by high concentrations of hydrogen sulfide are devoid of macrofauna (Duval and others 1980). Increased habitat associated with log debris is likely to be most beneficial to those organisms inhabiting the upper portions of the intertidal zone characterized by "old drift" (Waelti and MacLeod 1971).

## IMPACTS OF BARK AND DEBRIS ACCUMULATION

Most of the impacts of log handling on benthic and intertidal invertebrates have been attributed to the accumulation of bark and other debris at log-transfer and storage areas. Although the direct effects of substrate disturbance at these sites are relatively localized, bark and wood debris can spread beyond the immediate area of log dumping, sorting, or storage operations (Conlan 1977). Measured spatial extents of debris accumulation have ranged from only scattered deposits below subtidal log-storage sites (Ellis 1973, Pease 1974) to about 1 ha (Schultz and Berg 1976) to continuous debris accumulations covering areas up to 1 km<sup>2</sup> around active and abandoned dump sites (Conlan 1977).

The documented impacts of debris and bark deposits on benthic invertebrates are related to chemical changes in the environment (depletion of oxygen, toxic levels of hydrogen sulfide, and wood leachates), and to physical changes in sediment composition (increased amounts of wood and bark on top of and within the sediments). The extent of these physical changes depends on the amount of tidal flushing in the log-handling area; the methods used to dump, sort, and store logs; and the length of time the area has been used for log handling.

## CHEMICAL EFFECTS

Some authors have suggested that the chemical effects associated with bark- and wood-debris accumulations have a minor impact on benthic organisms. Studies by Pease (1974) and Schaumburg (1973) indicate that the BOD of these materials is low enough that oxygen levels in waters within or above the substrate are generally unaffected or at least not significantly changed from those normally associated with marine sediments. Similarly, the opportunity for dilution available in most log-handling areas usually prevents accumulation of hydrogen sulfide or wood leachates in the water column. Exceptions have been documented in

poorly flushed areas where extensive debris has accumulated on the substrate. For example, Pease (1974) found one log-dumping site in southeastern Alaska where low oxygen and high hydrogen sulfide concentrations and wood leachates were associated with a virtual absence of benthic fauna. Ellis (1973) also reported that epibenthic organisms were less abundant in log-handling areas where thick layers of decomposing bark and wood debris were deposited. The latter study, however, was based only on divers' observations; as a result, the effects of low oxygen and high hydrogen sulfide concentrations could not be distinguished from the concurrent physical changes in sediment composition. Because a relatively large proportion (4208 ha or 47 percent) of the British Columbia log-handling lease areas in water that were examined by FERIC (1980) were located in areas with negligible tidal currents, the potential for chemical impacts to benthic invertebrate communities may exist at several coastal British Columbia log-handling sites.

Conlan (1975) stated that quantitative information was lacking on the accumulation of leachates or hydrogen sulfide in interstitial or intertidal environments near log-handling sites. Both of these environments are directly affected by the decomposition of bark and wood deposits, and some may have limited flushing potential. Although hydrogen sulfide is toxic to some fish (McKee and Wolf 1963), marine benthic infauna are normally exposed to hydrogen sulfide produced by decomposition in the sediments and are unlikely to be greatly affected by the additional hydrogen sulfide associated with decomposition of bark and wood debris. On the other hand, some epifauna and pelagic invertebrates (for example, zooplankton) could be adversely affected by hydrogen sulfide accumulating in the water column of poorly flushed areas. No data are available on the toxicity of hydrogen sulfide to epibenthic and pelagic marine invertebrates.

The potential toxicity of log leachates to marine fauna is negligible because of the tendency for lignin constituents to precipitate with divalent cations in seawater (Schaumburg 1973). Nevertheless, accumulation of leachates in freshwater or slightly brackish log-handling areas--such as the tidal portion of rivers--still represents an area of possible impact, primarily because of the effects of plicatic acid on the pH of these poorly buffered waters (Peters 1974). The toxicity of log leachates to marine and freshwater invertebrates has been examined in laboratory bioassays by Buchanan and others (1976) and Peters and others (1976), respectively. Peters and others (1976) reported that the 96-h LC<sub>50</sub> (concentration required to produce 50-percent mortality of test organisms within a specified time) of western redcedar leachates to mayfly nymphs (Ephemerella inermis Eaton) was 4.4 mg/liter. The lower toxicity of log leachates in marine environments is substantiated by the studies of Buchanan and others (1976), who examined the effects of spruce and hemlock leachates on larval and adult pink shrimp (Pandalus borealis Kroyer) and larval Dungeness crab (Cancer magister Dana). The 96-h LC<sub>50</sub> of spruce extracts to larval shrimp, adult shrimp, and larval crabs was 415, 205, and 530 mg/liter, respectively; the hemlock extracts were only slightly toxic (96-h LC<sub>50</sub> was 1000 mg/liter) to adult shrimp and nontoxic to both shrimp and crab juveniles. By comparison, the highest leachate concentrations observed in nature (280 to 320 mg/liter) were those measured by Pease (1974) in a poorly flushed, Alaskan log-storage site. These concentrations were about five times the threshold concentrations for acute toxicity determined by the same author in laboratory bioassays with pink salmon fry, but bioassays were not conducted at the storage site to determine if these receiving waters were actually toxic to benthic fauna.

In summary, the potential chemical effects of debris accumulation to benthic and intertidal fauna remain poorly defined. In most log-handling areas, significant impacts are unlikely, although several relatively serious data deficiencies do exist. Of particular concern is the lack of data describing potential effects of hydrogen sulfide and leachates (sublethal and lethal) in log-handling sites with negligible tidal flushing, which according to the recent survey of FERIC (1980) account for about 47 percent by area of log-handling sites in British Columbia.

## PHYSICAL EFFECTS

The most thorough examination of the physical effects of bark and debris accumulation on benthic infaunal organisms was made by Conlan (1977) at Mill Bay, British Columbia. In this study, the physical effects of debris were clearly separated from the concurrent effects of chemical changes in the environment. The sand-bottom habitat in control areas with no debris accumulation was characterized by a wide diversity of organisms, including suspension-feeding bivalves and polychaetes. In areas with debris accumulation, the benthic community was altered in the following ways:

- Suspension-feeding organisms were eliminated.
- Dominant species were fewer and invertebrate biomass was less than in control areas.
- Numbers of wood-boring bivalves (Bankia sp.) and isopods (Limnoria sp.) were greater than in control areas.



Conlan (1977) also found that these effects were particularly evident where depth of debris exceeded 1 cm. Areas that had been abandoned for 17 years or more showed little recovery in normal community structure and abundance. Her results were generally consistent with those of earlier investigations of benthic infauna at active and abandoned log-handling areas (Conlan and Ellis 1979, Pease 1974) and demonstrated that, although the changes to infauna are not necessarily pronounced, they are measurable.

In general, the accumulation of bark and debris has had little adverse effect on epibenthic communities. In areas with thick, soft deposits of decomposing bark but no sunken logs, Ellis (1973) reported fewer epibenthic species (such as crabs) and attached forms (including anemones and tunicates). At sites where scattered bark and sunken log debris provided additional habitat, however, Conlan and Ellis (1979), Ellis (1973), McDaniel (1973), and Pease (1974) all reported increased abundance of epibenthic fauna, particularly amphipods, Munida sp., shrimp, crabs, anemones, and tunicates. In sunken logs and accumulations of wood debris, wood-boring bivalves and isopods were numerous. Although the increased habitat for wood-boring organisms would be considered a positive impact of log handling biologically, it is a negative impact of log-handling operations.

The evidence to date therefore suggests that the infaunal suspension-feeding organisms (living within the sediment) are adversely affected by the physical changes associated with accumulation of bark and wood debris, while the epibenthic organisms remain generally unaffected or sometimes may benefit from increased habitat. The only situation where adverse impacts to epifauna have been indicated is where decomposition of bark debris results in a soft, flocculent substrate (Conlan 1977).

## SUMMARY OF IMPACTS

A summary of various physical and chemical effects associated with log handling on benthic and intertidal invertebrates is provided in table 6. For some categories of effects, such as those related to chemical changes in benthic habitats, limited information is available on which to base assessments, while other types of effects are better documented. For each type of disturbance indicated in table 6, degree is largely determined by the spatial extent of the log-handling operation; its location with respect to potentially sensitive areas, such as estuaries; and the ecological, commercial, or recreational importance of affected resources. On a regional basis, impacts on benthos associated with accumulation of bark and wood debris are rated as minor to moderate as a result of apparent slow recovery of the substrate of many areas that have been inundated with debris, although site-specific impacts to benthic invertebrates can be moderate to major.

In conclusion, the most significant negative impacts of log handling are destruction of habitat and crushing of benthic organisms in intertidal log-storage sites, and alteration of benthic infauna habitat and abundance as a result of wood-debris and bark accumulations from dumping and water sorting, and, to a lesser extent, from log storage. Both of these forms of impact have been documented from log-handling sites on the west coast, and have sometimes been responsible for local reductions in commercially important bivalve populations (clams and oysters), reductions in fish-food organisms (suspension-feeding polychaetes), and increases in wood-boring forms.

Table 6--Summary of log-handling impacts on benthic and intertidal invertebrates

Log-handling effect	Major source of effect		Positive impacts	Mode of action	Negative impacts	Mode of action
Bottom scouring	Free-fall dumping in shallow waters (including barge dumping); tug wash in shallow estuaries		None	--	Crushing of epifaunal and infaunal species; habitat disturbance	Direct
Sediment compaction	Free-fall dumping in shallow waters and intertidal log storage		Possible increase in abundance of some species of mobile epifauna such as harpacticoids	Indirect	Destruction of habitat and crushing of suspension-feeding fauna (bivalves, polychaetes); decrease of infauna and sedentary species of epifauna	Indirect; direct
Bark and debris accumulations: lowered oxygen levels; toxic accumulations of H <sub>2</sub> S and log leachates	Free-fall dumping; water sorting; log storage is generally a minor contributor		None	--	Mortality of epifauna and infauna; potential sublethal effects resulting in altered secondary production	Direct
Physical changes in sediment and bottom composition	Free-fall dumping and water sorting; flat-rafting may contribute to log sinkers		Increased abundance of epifauna where scattered bark and debris provide additional habitat and attachment sites (wood-boring species, amphipods, shrimp, prawns, crabs, tunicates, nonburrowing anemones)	Indirect	Infauna--decreased biomass, elimination of suspension-feeders (bivalves and polychaetes); lower species diversity  Epifauna--reduced abundance when bark and debris have decomposed to soft, flocculent consistency	Indirect
Time considerations						
	Short-term (<10 yr)	Long-term (>10 yr)	Space considerations	Probable recovery potential (years)	Degree of impacts	Factors influencing degree of impacts
Bottom scouring	X	None	Insignificant area of impact in relation to available habitat	<5	Insignificant to minor	Dumping or other activities causing scouring in important areas, such as estuaries or commercial/recreational shellfish-harvesting areas, would lead to minor impact
Sediment compaction	X	If site used continuously	Insignificant area for dumping; insignificant to moderate area for rafting-storage areas	<5	Insignificant to moderate (moderate when site used 10 years)	Large storage areas in important estuaries or commercial/recreational shellfish-harvesting areas; duration of use of log-handling area
Bark and debris accumulations: lowered oxygen levels; toxic accumulations of H <sub>2</sub> S and log leachates	X	None	Insignificant to moderate depending on tidal flushing and log-handling techniques	<5 (depending on rate of decomposition)	Insignificant to moderate	Few reported instances; lack of information for benthic environments; dumping and sorting in important estuaries or commercial/recreational shellfish areas may increase impacts
Physical changes in sediment and bottom composition	None	X	Minor to moderate, depending on tidal flushing and log-handling techniques	<5	Minor to moderate	Extent of debris coverage; importance of area: important estuary or commercial/recreational shellfish-harvesting area

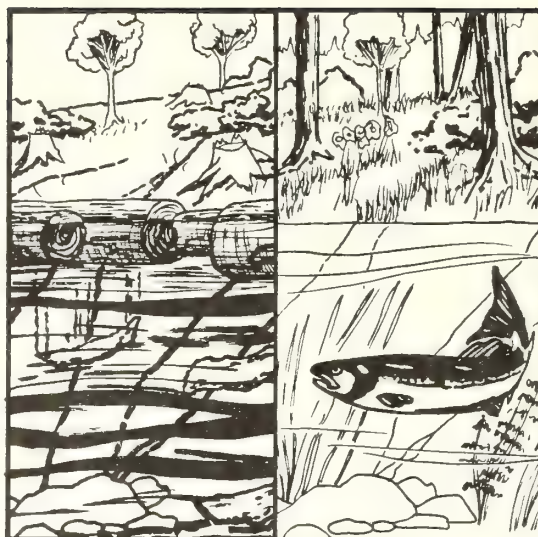
-- = not applicable

Some benthic invertebrates benefit from log-handling activities. These are primarily epibenthic species, which increase in abundance in log-storage areas characterized by scattered deposits of bark and wood debris. These species include wood-boring bivalves and isopods, nonburrowing sea anemones, barnacles, tunicates, amphipods, *Mundia* sp. (in deeper waters), shrimp, and harpacticoid copepods. Some of these invertebrates are important fish-food organisms (amphipods and copepods) or potential commercial species (shrimp, prawns, and crabs).

## DATA DEFICIENCIES

Major data deficiencies that have limited assessment of the impacts of various aspects of log handling on benthic and intertidal invertebrates include:

- Information related to the concentration of hydrogen sulfide and log leachates in poorly flushed interstitial and pelagic habitats, and the potential toxic and sublethal effects of these chemicals on benthic infauna, epifauna, and pelagic invertebrates.
- Data describing potential sublethal effects of physical and chemical changes resulting from accumulation of bark and wood debris, particularly information describing the bioenergetic effects of log handling on estuarine and intertidal benthic invertebrate communities.
- Quantitative data describing the relative effects of intertidal flat-raft and bundle-boom storage on the degree of sediment compaction, redox potential, and subsequent impacts to benthic infauna.
- Information describing the effects of log storage (both intertidal and subtidal) on the community structure and abundance of sedentary and mobile epifauna.



## IMPACTS OF LOG HANDLING ON FISH

Fish species that may inhabit the areas most frequently used for log handling (estuaries, sheltered bays, and inlets) include the anadromous salmonid species (salmon, cutthroat and rainbow trout, Dolly Varden), marine smelts (surf smelts, capelin, longfin smelt, eulachon), herring, various rockfish, and bottom-dwelling fish species. In addition to the commercial and recreational importance of some of these species, many also represent important prey species for marine mammals and aquatic birds. The life-history phases of these fishes that are most likely to be affected by log handling include rearing (all species), migration (salmonids, smelts), and spawning and incubation (smelts, herring). The timing of the life-history phases for important fish species found in Pacific Northwest coastal waters is presented in table 7.

The direct impacts of log handling on fish have not been quantitatively assessed except by Levy and others (1982). The following sections therefore describe probable effects of log handling, based on observations of other communities, such as benthic invertebrates, and on indirect evidence of impacts cited in the few references available on this topic.



Table 7--Life-history phases of some important fish in British Columbia coastal waters

Fish	Activity	Month											
		J	F	M	A	M	J	J	A	S	O	N	D
Salmonids	Fry/smolt estuary <sup>1/</sup> residence	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
	Adult migration staging	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Herring	Spawning activity	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
	Rearing activity	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Surf smelt	Spawning and incubation	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
	Residence	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Capelin	Spawning and incubation	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Longfin smelt	Adult migration	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
	Residence	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
Eulachon	Adult migration and recovery	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----

<sup>1/</sup> Information on timing from Hart (1973).

## DIRECT IMPACTS

The most comprehensive study of fish densities, growth, and feeding behavior was conducted in the Fraser River estuary (Levy and others 1982). Within the north arm of the estuary, a pristine marsh was compared with a marsh with extensive log-storage booms. Levy and others (1982) found salmonid fish densities to be similar in both areas. They concluded juvenile salmon did not avoid stored-log booms in this well-flushed estuary. They also found chinook salmon fry in the log-storage area to be significantly larger than in the pristine marsh site (one-way ANOVA results:  $F_{2,240} = 6.03$ ,  $p < 0.01$ ). Their data indicate that growth conditions may be relatively good for chinook fry in the log-storage area. They found no size or growth-potential differences between log-storage areas and the pristine marsh for chum salmon fry.

Juvenile salmon in two adjacent intertidal areas of the Fraser estuary, the Point Grey log-storage area, and the Musqueam Marsh displayed major dietary differences (Levy and others 1982). This dietary shift in the log-

storage area appeared to be caused by a decrease in estuarine insects because marsh plants were absent there and the mysid *Neomysis mercedis* and fish larvae were more available.

Levy and others (1982, p. 66) concluded that "in spite of the drastic physical impact of intertidal log storage at Point Grey there was no strong negative effect on fish utilization of the area. There were no decreases in fish abundance, or fish growth that could be attributed to the presence of stored log booms." Because the Point Grey log-storage area is well flushed, they suggest research is needed to test the hypothesis that fish also do not avoid log booms in poorly flushed log-storage areas.

Potential direct effects of log handling on fish may result from physical disturbances associated with log-transfer and sorting activities. Physical effects, such as bark accumulation, may suffocate incubating eggs or interfere with fish habitat use. Direct impacts may also result from the chemical effects of log leachates released from stored logs and the oxygen demand of decomposing wood and

bark debris at log dumps and, to a lesser extent, log-storage sites. No information on the importance of these direct disturbances to fish populations is available, however.

Large numbers of salmon occur in many rivers, estuaries, and coastal areas during the periods of juvenile rearing, as well as during adult spawning migrations to natal streams (Levy and others 1979, Neave 1966, Scott and Crossman 1973, Stasko and others 1973), while anadromous cutthroat trout, Dolly Varden, and steelhead trout may use some of these coastal environments throughout the year (Scott and Crossman 1973). Other species, including smelt and herring, may concentrate in estuaries, inlets, and bays during their spawning and migration periods (table 7). Only the surf smelt, capelin, and herring spawn and deposit eggs in marine environments potentially used for log handling, however (Hart 1973). Quantitative assessment of impacts is impossible because direct effects of log handling on fish have not been studied. Log-transfer and sorting activities, however, are unlikely to interfere significantly and directly with fish outside the relatively small area where the disturbances occur, and fish would probably avoid such areas. Nevertheless, log dumping, tugboat wash during sorting, and intertidal log storage may destroy some of the incubating eggs of smelt and herring. Other fish, including shallow-water rockfish and bottom-dwelling species, are widely distributed in coastal British Columbia, southeastern Alaska, and Puget Sound waters. The areas used for log handling represent only a minor portion of their available habitat. Note, however, that no data are available to describe the site-specific impacts of log handling on the limited, unique habitats for some fish resources and the potential for disproportionate effects of these activities on fisheries productivity.

The potential chemical effects of log leachates on fish have been examined in several laboratory bioassays and in limited field studies, including those of Pease (1974) and Schaumburg (1973). In laboratory experiments, log leachates have been shown to be toxic to fish and also to contribute to increased chemical oxygen demand in the water. The toxicity of leachates is significantly lower in sea water and in marine environments with low salinity (<20 parts per thousand) than in fresh water, however. Both Pease (1974) and Schaumburg (1973) concluded that the large volume of water available for dilution usually prevents either accumulation of leachates to toxic concentrations or reduction in oxygen concentration that could adversely affect fish. Any increase in leachate concentration that could be toxic would usually be temporary and extremely localized. Of 13 active or inactive dumping and storage areas examined by Pease (1974) in southeastern Alaska, only one site (with limited tidal flushing and heavy debris accumulation) had leachate and oxygen concentrations that could adversely affect fish. No information is available, however, on the frequency of this type of occurrence in British Columbia. The relatively high proportion (47 percent) of coastal British Columbia log-handling sites reported to have negligible tidal flushing (FERIC 1980) suggests that direct chemical impacts of this type may occur in some areas.

## INDIRECT IMPACTS

Alterations in fish habitat or in the abundance of fish-food organisms may indirectly affect fish populations either positively or negatively. For example, FERIC (1980) reported that many coastal log-handling sites in British Columbia are located in intertidal or estuarine areas (3374 ha; 37 percent). Many of these areas support communities of eelgrass, rockweed, or both--which are common substrate for deposition of herring spawn (Outram and Humphreys 1974, Patterson 1975). Several authors suggest that the abundance of aquatic flora has been significantly reduced in

some intertidal areas used for log storage (for example, Ladysmith Harbour, Nanaimo and Squamish River estuaries) through shading (Ministry of Environment, British Columbia 1976; Waldichuk 1979), grounding of rafts with resultant scouring and compaction of sediments (Pease 1974, Sibert and Harpham 1979, Waldichuk 1979), and uprooting of plants resulting from tugboat activity (Sibert 1978). These impacts may be responsible for elimination of herring-spawn deposition in Ladysmith Harbour near Dunsmuir Island (Patterson 1975) and in the Mamquam Channel area of the Squamish River estuary (Hoos and Vold 1975). No evidence suggests, however, that herring losses have resulted. Healey (1978) suggested that intertidal log storage has resulted in the destruction of some juvenile salmon rearing-habitat in the central and western portions of the Nanaimo River estuary, although quantitative data to substantiate his hypothesis are apparently lacking.

The abundance of benthic epifauna and infauna, which may be important fish food, is also reported to be decreased in some areas where bark and wood debris accumulate or where intertidal log storage occurs (Conlan 1977, Ellis 1973, Pease 1974). As a result, fish populations using these nearshore environments may be indirectly affected. At the same time, despite reductions in some invertebrate species, several fish-food organisms often appear to be more abundant in some areas where scattered log-debris and bark deposits occur. For example, Levings (1973) noted large populations of amphipods (Anisogammarus pugettensis Dana) in association with a dense diatom-chlorophyte community among older logs stored in the Squamish River estuary. Goodman and Vroom (1972) reported that salmonids using this area preyed on these amphipods. Similar indirect positive impacts of log handling have been recorded in the Kitimat River estuary (Higgins and Schouwenberg 1976, Paish and Assoc., Ltd. 1974); Conlan (1977) also reported that the abundance of amphipod species is either increased or unaffected by log storage.

Although some authors have inferred that compaction of sediments under intertidal log booms has contributed to a decrease in benthic amphipods and copepods that serve as major food items for juvenile salmon (Healey 1978, Waldichuk 1979), this relation has not been satisfactorily demonstrated. Sibert (1978) and Sibert and Harpham (1979) reported that, although larger infauna were removed from log-storage areas of the Nanaimo River estuary, the total abundance of major meiofauna taxa, nematodes, and harpacticoid copepods (important prey items of juvenile chum salmon) could not be related to the presence of log booms.

Some observations also suggest that some fish species, including prey species of marine mammals, may be attracted to areas where logs are stored or where wood and bark debris increases the abundance of food sources. In areas of undecayed bark and debris accumulation, Ellis (1973) found sandlance, species of blennies and cottids, as well as yellowfin sole, using habitat under log-storage areas in Hanus Bay, Alaska. Schultz and Berg (1976) also reported fish species--such as cod, shiner, perch, and searcher--in association with submerged logs, branches, and benthic bark deposits in southeastern Alaska.

Apparently, therefore, the allegations that log dumping, sorting, and storage have contributed to reduction in fish habitat and fish-food organisms are based on circumstantial evidence.

One frustrating aspect of our concern for the environment is the lack of research data to support decisions. With the exception of the Nanaimo River estuary on southeastern Vancouver Island, no comprehensive ecological study of log-rafting and storage impacts on the total estuary has been made. Intertidal habitats have been well documented near mill sites in Oregon, Washington, and British Columbia. Leachate toxicity and BOD problems, although well documented in





the laboratory, have not been documented in the field. Environmental concerns related to log transportation in south-eastern Alaska are poorly based in fact; a well-organized study of the estuarine ecosystem should be conducted on both benthic and epibenthic organisms.

## SUMMARY OF SIGNIFICANT IMPACTS

Assessment of log-handling impacts on fish is limited by the lack of direct quantitative information. Most of the alleged negative impacts of log handling on fish are speculative, based on few observations and no quantitative studies. A summary of potential direct and indirect impacts of log handling on fish is provided in table 8. The degree of potential negative impact to coastal British Columbia and southeastern Alaska fish resources probably ranges from insignificant to minor. The greatest potential for negative impacts is from the destruction of herring spawning areas. Other negative impacts are probably relatively localized and not likely to have serious effects on fish.

Some observations also suggest that positive indirect impacts to fish may result from increased abundance of invertebrate food organisms in some areas of log storage and log-debris accumulation.

## DATA DEFICIENCIES

The following data deficiencies have severely hampered delineating the impacts of log handling on coastal British Columbia fishery resources:

- Few studies have addressed the direct or indirect effects of dumping and log sorting on fish in log-handling areas, particularly on rearing juvenile salmonids or migratory adults.
- No adequate study has been conducted of the impact of the loss of eelgrass beds on herring populations in log-storage areas.
- Studies have not been conducted on sublethal effects of log leachates on fish in their natural habitat.
- Information is lacking on concentrations of leachates or leachate-derived chemicals in British Columbia log-handling areas.

Table 8--Summary of log-handling impacts on fish

Log-handling effect	Major source of effect		Positive impacts	Mode of action	Negative impacts	Mode of action
Physical disturbance to water column and bottom	Free-fall dumping; water sorting in shallows; intertidal log storage		None	--	Disturbance to fish present; destruction of herring and smelt spawn	Direct
Accumulation of bark and log debris and floating materials	Log storage and bark- and wood-debris accumulations at dump and water-sorting areas		Increased abundance of some fish-food organisms; possible attraction of some species to log-raft or debris habitats	Indirect	Toxicity or sublethal effects from log leachates and low dissolved oxygen	Direct
					Loss of fish-food organisms in areas of heavy debris accumulation	Indirect
Bottom compaction and scouring	Free-fall dumping; water sorting; intertidal log storage		None	--	Loss of aquatic plants for herring spawning; loss of invertebrate food organisms	Indirect
Time considerations						
	Short-term (<10 yr)	Long-term (>10 yr)	Space considerations	Probable recovery potential (years)	Degree of impacts	Factors affecting degree of impacts
Physical disturbance to water column and bottom	X	None	Localized; areas of fish use are site- and time-specific	<5	Insignificant to minor	Fish use depends on time of year and is restricted to some areas (no documented evidence of impact)
Accumulation of bark and log debris and floating materials	X	None	Localized and depends on the degree of available dilution	<5	Insignificant	Toxicity-related impacts may increase with decrease in salinity and decrease in degree of tidal flushing (no documented instance of toxicity to fish in field)
			Restricted to areas of debris accumulation	>5	Insignificant to minor	Advanced decay of bottom debris will reduce invertebrate food sources
Bottom compaction and scouring	X	None	Restricted mainly to areas of direct bottom disturbance	>5	Insignificant to moderate (potential)	Importance of spawning area and aerial extent of disturbance determine site-specific impact (no documentation of effects to fish populations)

-- = not applicable

## INTENSITY OF LOG RAFTING AND FOREST OPERATIONS: REGIONAL DIFFERENCES

The history of development of the timber industry in western North America reflects geographical patterns. The shipping and cargo mills described earlier led to the development and persistence of processing centers located to accommodate both railways and seaports. The interiors of British Columbia, Washington, Oregon, Idaho, Montana, and northern California developed with the railroads and the mining industry. The problems and phasing of log handling in fresh water are different from those in salt water.

The freshwater problems are largely historical. Although the extent and pervasive impact on western rivers is impressive, physical alterations do not exist entirely as a result of log handling. They persist because of log-salvage policies for road and bridge protection, flood reduction, and debris control, and because of current fish-habitat management guidelines.

Degradation of water quality has eased considerably because of new laws and better enforcement. Economic factors have played a large part by the continual closing and consolidation of wood-processing facilities. McHugh and others (1964) reported that about 4860 ha of log ponds and 800 ha of sloughs

or canals used as log-storage sites existed in Oregon; in Washington, about 1620 ha of log ponds and 600 ha of sloughs were used for log storage; northern California had about 1620 ha and Idaho had 400 ha. The size of the ponds varied from less than 1 ha to over 160 ha in surface area and from 1 m to 9 m in depth. These figures are probably half as large now, because of mill closures and dry-land sorting and processing.

Lumber production in the western United States is illustrated in figure 4. The use of water for log storage and transportation in the West reflects the same trends that were seen in Washington during its peak transfer production in the late 1920's. Oregon did not reach a peak until the late 1950's and early 1960's. Large-scale timber production did not begin in Alaska until pulp mills were built at Ketchikan and Sitka in the mid-1950's and early 1960's. Timber production in south-eastern Alaska reached a peak in the early 1970's. British Columbia reached a peak at the end of the 1970's. With improvement in the world economy, this upward trend should continue. The greatest use of water for transportation in Idaho and Montana occurred between 1906 and 1929 with mills located on the shores of the large lakes (Pend Oreille, Coeur d'Alene, and Flathead). These lakes experienced significant log traffic during this period. California's timber production peaked in the mid-1920's and again in the mid-1950's. Along the coast of California, river transportation of logs declined to the point where it no longer seriously affected fish habitat by 1890, particularly in the Monterey Bay area and in Mendocino County, north of San Francisco Bay; log storage similarly declined by 1920.

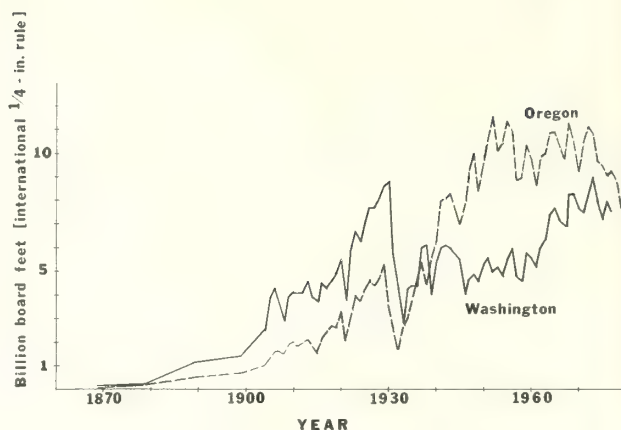
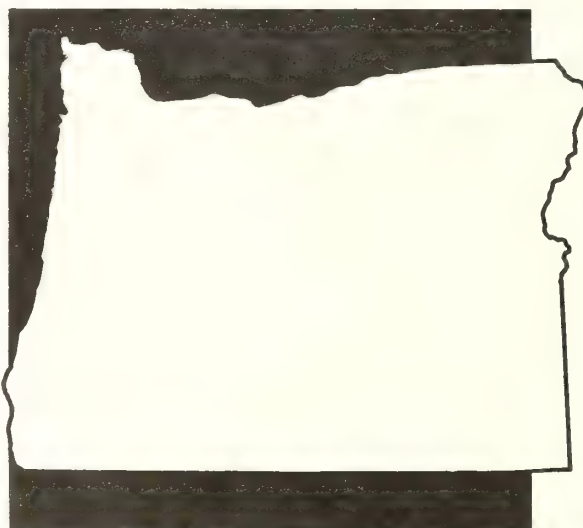


Figure 4.--Lumber production in Oregon and Washington, 1869-1980.

## HISTORICAL INTENSITY OF LOG RAFTING IN WESTERN NORTH AMERICA



OREGON

Oregon's major rivers, the Columbia and Willamette, have been used intensively from the beginning of timber production to the present for log handling and transportation. Its estuaries were also used intensively. For perspective, Oregon's estuaries are shown in table 9, starting at the northern border and moving to the south, along with surface areas, percent tide-lands, and size of drainage basins. Estuary surface areas are from work by Johnson (1972), Marriage (1958), Oregon Division of State Lands (1973), and Percy and others (1974). Marriage did



Table 9--Surface areas, percent tidelands, and drainage areas of Oregon's estuaries (from Percy and others 1974)

Estuary	Surface area measured at			Surface area in tidelands	Drainage basin area
	High water	Mean high tide	Other		
	Hectares			Percent	km <sup>2</sup>
Youngs Bay	--	--	1/1 162.4	-- --	312.8
Necanicum	--	--	2/112.6	-- --	233.1
Nehalem	967.1	935.2	3/1 525.2	32 47	2 192.3
Tillamook	3 588.7	3 357.1	3/3 579.8	58 50	1 384.6
Netarts	88.5	941.6	3/974.4	-- 65	35.9
Sand Lake	178.8	213.8	3/283.5	-- 75	43.6
Nestucca	413.9	405.0	465.4	-- 85	825.6
Salmon River	69.3	82.6	3/177.4	57 62	192.3
Siletz	439.8	480.7	487.2	-- 65	956.4
Yaquina	1 714.4	1 583.6	1/1 162.4	61 35	648.7
Alsea	866.7	869.1	3/909.9	-- 46	1 215.4
Siuslaw	590.5	909.2	643.6	38 34	1 982.1
Umpqua	2 733.4	2 766.2	2 313.4	27 22	11 692.3
Coos	4 444.1	--	3 864.9	48 --	1 551.3
Coquille	331.3	--	3/284.7	-- --	2 712.8
Sixes	--	--	133.7	-- --	330.8
Elk	--	--	4/117.5	-- --	241.0
Rogue	232.9	--	--	-- --	13 076.9
Pistol	--	--	4/93.2	-- --	271.8
Chetco	56.7	--	--	-- --	920.5
Winchuck	--	--	4/52.7	-- --	179.5

-- = no data available.

1/ Area calculated by planimeter; shoreline representing approximate line of mean high water.

2/ Tidal stage not given; described as "the estuary covers 278 acres."

3/ Tidal stage not given; described as "those areas affected by tidal action."

4/ Area calculated by planimeter from aerial photographs; tidal stage not known.

not specify the relation of the tidal stage to the areas, but he did state that "only those areas affected by tidal actions were included in the acreage measurements." He determined the areas sometime around 1948 from either U.S. Coast and Geodetic Survey (USCGS) bay charts (preferably) or coastal charts, but made no indication as to which type was used for the individual estuaries. He also usually recorded the number of tideland acres. Johnson apparently used USCGS charts from the late 1960's and early 1970's to determine surface areas. The Oregon Division of State Lands (1973) obtained mean low tide and mean high tide surface areas by planimeter measurements taken from aerial photographs on which estuarine boundaries at those tidal stages had been marked by direct

observation. That agency has also compiled a tideland abstract listing the acreage of most Oregon estuary tidelands, as well as ownership and deed information.

Log-processing and shipping centers in Oregon are located in nine major areas that have an impact on aquatic environments: Coos Bay, Umpqua River mouth, Siuslaw Bay, Yaquina Bay, Tillamook Bay, Youngs Bay, the Columbia River estuary, the Columbia River between its mouth and Bonneville Dam (Portland), and the Willamette River around Oregon City. Currently, about 35 percent of the 7 billion board feet per year are towed in these areas. The trends in intensity of use are reflected in figure 5. Coos Bay has two pulp mills and a large lumber- and log-shipping facility. From 1935 until

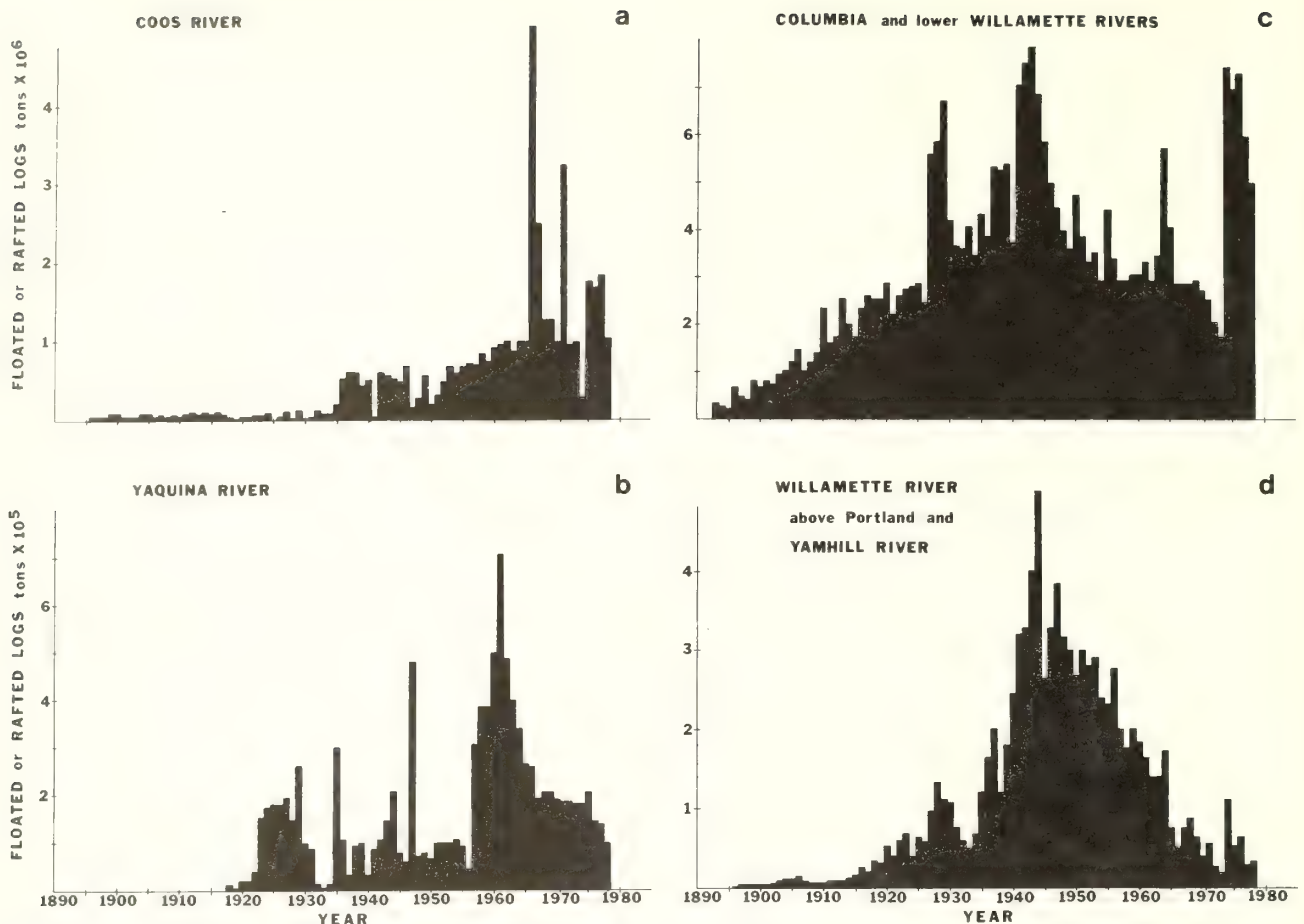


Figure 5.--Amount of logs floated or rafted on Oregon rivers, a. Coos River, 1895-1978; b. Yaquina River, 1918-1978; c. Columbia and lower Willamette Rivers, 1893-1978; d. Willamette River above Portland and Yamhill River, 1896-1978.

the present, the volume of logs towed in the bay generally ranged between 200 and 600 million board feet annually (fig. 5a). Yaquina Bay (fig. 5b) reflects a late start on the coast because of a forest fire in the 1860's. The Georgia Pacific Pulp Mill went into production in 1957, and the log flow increased three-fold. From 1962 until the present, use of the bay has declined because of decreased logging production and more dry-land sorting and storage in response to environmental regulation.

The Columbia and Willamette rivers were used before 1890. Records show a steady increase in log traffic in the Columbia River (fig. 5c), which peaked during World War II (WWII) and then declined until the housing boom of the mid-1970's when the first cutover land along the lower Columbia started to yield its second crop. Generally,

between 1 and 2 billion board feet of lumber per year have been towed on the Columbia River since 1930. The mills at Longview and Portland at the mouth of the Willamette were and are major lumber centers, although Longview is a much more important center today. Logs from the early timber cutting in the Willamette River Basin were in large part transported down the Willamette to these Portland-area mills. The logs transported in the Willamette River essentially supplied the lower Columbia with logs from 1938 to 1957 (fig. 5d) as the peak of the Columbia production passed.

The U.S. Army Corps of Engineers prepared a map in 1935 (fig. 6) that showed the potential log traffic through the Oregon City Locks from the Willamette Basin to Portland and Columbia River sawmills. It greatly underestimated the potential traffic.

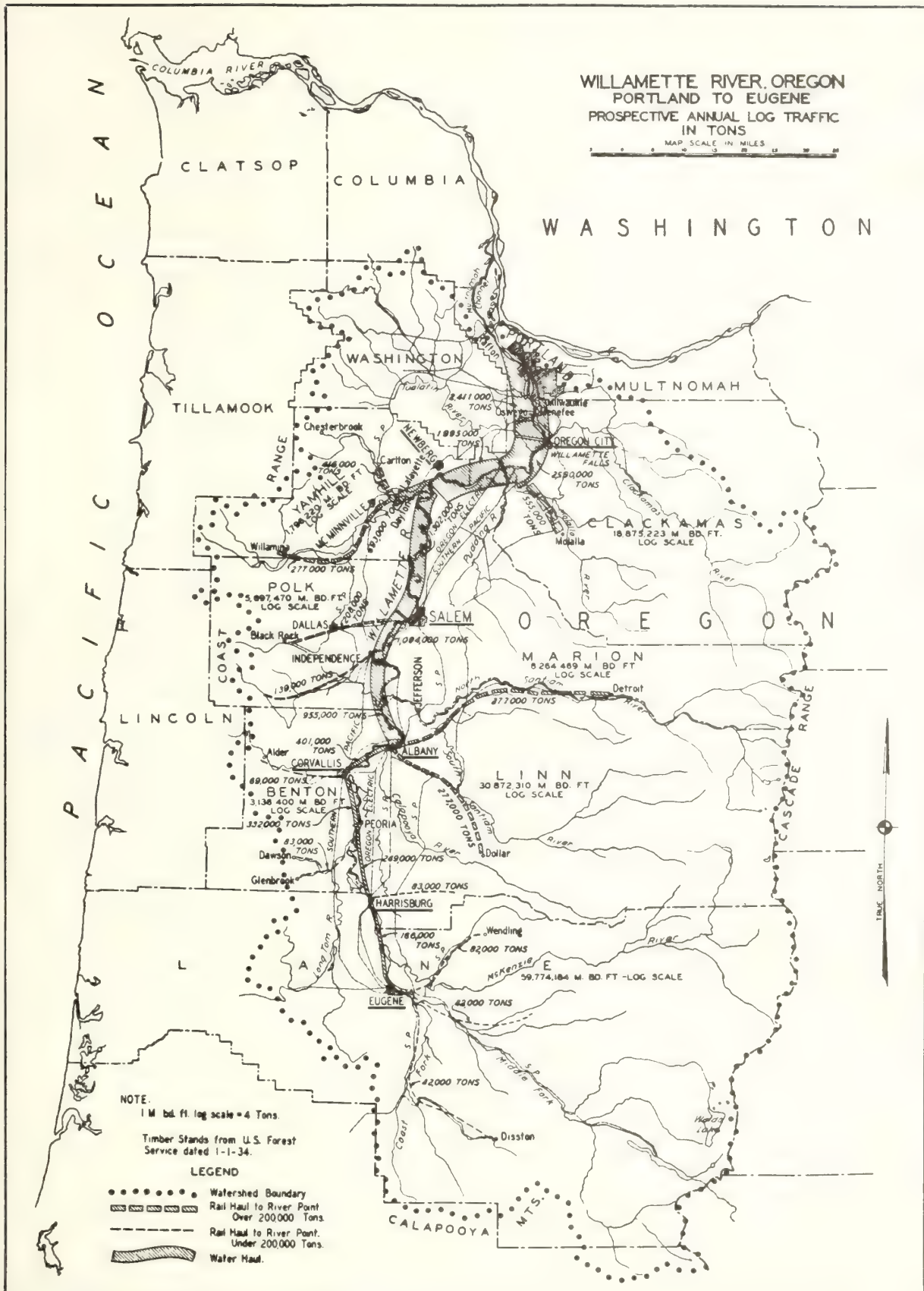


Figure 6.--In 1935, the U.S. Army Engineers prepared this map to show the potential log traffic through Oregon City locks, from the Willamette Basin to Portland and Columbia River sawmills. It greatly underestimated the potential traffic (U.S. Army Corps of Engineers 1937).



Major log-dump sites and storage sites are shown on this map. During WWII, over 1 billion board feet were annually transported down the Willamette River. This activity ceased as processing centers moved closer to the supply of logs (Cornwall 1941).



WASHINGTON

In Washington, the Columbia River, Puget Sound, and Grays Harbor are the principal areas affected by log handling. Simenstad and others (1982) identified 96 coastal and inland estuaries in 14 regions of the State (table 10). Estuaries within these regions are structurally, hydrologically, and biologically diverse, and range in size from drowned river valleys, which characterize major estuaries (for example, Grays Harbor and Skagit Bay/Port Susan) to the numerous small stream-channel estuaries

characteristic of Puget Sound, Strait of Juan de Fuca, southeastern Alaska, and much of British Columbia. One region, the island archipelago of northern Puget Sound, has no major estuaries, but is greatly influenced by freshwater outflow from the Fraser (British Columbia) and Skagit rivers.

Like most west coast estuaries, Washington's have undergone extensive changes since the area was first settled. These changes were either directly to the natural estuarine environment or indirectly through alteration of freshwater habitats by log drives, urbanization, and diking in their contributing watersheds. Currently, the U.S. Army Corps of Engineers removes 2.3 million m<sup>3</sup> of sediments annually from Washington estuaries as part of maintenance dredging operations, nearly half of this from Grays Harbor (cited in Simenstad and others 1982). Although changes in most west coast estuaries have not been quantified, Bortleson and others (1980) have reported changes in 11 major estuaries of Puget Sound. Such estuaries as the Duwamish and Puyallup River deltas have lost essentially all their original wetland habitat. Although most smaller, less-urbanized estuaries in both Oregon and Washington escaped such devastation, most now have road causeways or dikes that usually altered the natural estuarine hydraulics. Thus, assigning a cause to a biological impact is extremely difficult. Quantitative information relating changes in estuarine habitats to changes in populations of salmonids and other estuarine fishes is distinctly lacking (Dorcy and others 1978, Simenstad and others 1982).

Table 10--Principal estuaries in Washington State, not including the Columbia River; data sources were Smith and others (1977), U.S. Army Corps of Engineers (1976), U.S. Geological Survey (1978, 1980), and Williams and others (1975)

Estuarine region	Estuaries	Principal watersheds	Drainage area	Average annual discharge	Annual maximum discharge	Extant estuarine area <sup>1/</sup>	Water-inventory areas <sup>2/</sup>
			(km <sup>2</sup> )	(hm <sup>3</sup> yr <sup>-1</sup> )	(m <sup>3</sup> sec <sup>-1</sup> )	(km <sup>2</sup> )	
North Sound	Drayton Harbor	Dakota Creek	75	--	--	--	01, 03 (part)
		California Creek	59	--	--	--	
	Bellingham Bay	Hooksack River	2139	3520	1060	13	
North Puget Sound	Samish Bay	Samish River	275	--	47	15	
	Port Townsend Bay	Chimacum Creek	87	--	--	--	02, 06 (part), 03 (part)
Skagit Bay/ Port Susan	Skagit Bay	Skagit River	8011	14900	4080	67	04, 05, 06 (part)
Possession Sound Central/South	Port Susan	Stillaguamish River	1772	2650	1785	24	
	Everett Harbor	Snohomish River	4439	8890	3260	19	07
	Shilshole Bay	Cedar River	487	625	250	--	08, 12, 14, 15 (part)
Puget Sound		Lake Washington	62	50	33	n.a.	
		Sammamish Lake	472	330	80	n.a.	
	Chambers Bay	Chambers Creek	48	--	--	--	
	Oyster Bay	Kennedy Creek	53	--	520	--	
	Skookum Inlet	Skookum Creek	--	--	--	--	
	Oakland Bay	Goldsborough Creek	--	--	--	400	
	Hammersley Inlet	Mill Creek	--	--	--	--	
	Case Inlet	Rucky Creek	--	--	--	--	
		Coulter Creek	--	--	--	--	
		Sherwood Creek	--	--	--	--	
	Burley Lagoon	Burley Creek	--	--	--	--	
	Gig Harbor	Crescent Creek	--	--	--	--	
	Olalla Bay	Olalla Creek	--	--	--	--	
	Sinclair Inlet	Gorst Creek	--	--	--	--	
	Dyes Inlet	Clear Creek	--	--	--	--	
		Strawberry Creek	--	--	--	--	
		Chico Creek	--	--	--	350	
	Liberty Bay	Dogfish Creek	--	--	--	--	
	Miller Bay	Grovers Creek	--	--	--	--	
	Port Ludlow	Ludlow Creek	--	--	--	--	
	Elliott Bay	Duwamish River	1140	1370	375	0.1	09
	Commencement Bay	Puyallup River	2455	3010	1610	0.1	10
	Nisqually Reach	Nisqually River	1339	1630	870	--	11 10
		McAllister Creek	--	--	--	--	
Budd Inlet	Capitol Lake	Deschutes	417	--	3380	--	13
Hood Canal	Lynch Cove	Union River	61	--	--	--	15 (part), 16, 17
	Big Mission Creek	Big Mission Creek	--	--	--	--	
	Tahuya River	Tahuya River	--	--	--	--	
	Annas Bay	Skokomish River	622	655	610	6.0	
	Dewatto Bay	Dewatto River	43	--	750	--	
	Lilliwaup Bay	Lilliwaup Creek	--	--	--	--	
	Hamma Hamma River	Hamma Hamma River	219	--	2260	--	
	Anderson Cove	Anderson Creek	--	--	--	--	
	Duckabush River	Duckabush River	172	370	255	--	
	Dosewallips River	Dosewallips River	--	--	--	--	
	Quilcene Bay	Big Quilcene River	--	--	--	--	
		Little Quilcene River	--	--	--	--	
	Jackson Cove	Maple Creek	--	--	--	--	
		Spencer Creek	--	--	--	--	
	Tarboo Bay	Tarboo Creek	32	--	--	--	
	Thorndyke Bay	Thorndyke Creek	31	--	--	--	
	Stavis Bay	Stavis Creek	--	--	--	--	
	Seabeck Bay	Seabeck Creek	--	--	--	--	
	Little Beef Harbor	Little Beef Creek	--	--	--	--	
	Big Beef Harbor	Big Beef Creek	36	35	20	--	
	Port Gamble	Gamble Creek	--	--	--	--	
		Miller Lake	--	--	--	--	
	Squamish Harbor	Shine Creek	--	--	--	--	

See footnotes at end of table.

Table 10--Principal estuaries in Washington State, not including the Columbia River; data sources were Smith and others (1977), U.S. Army Corps of Engineers (1976), U.S. Geological Survey (1978, 1980), and Williams and others (1975) (continued)

Estuarine region	Estuaries	Principal watersheds	Drainage area	Average annual discharge	Annual maximum discharge	Extant estuarine area <sup>1/</sup>	Water-inventory areas <sup>2/</sup>
			(km <sup>2</sup> )	(hm <sup>3</sup> yr <sup>-1</sup> )	(m <sup>3</sup> sec <sup>-1</sup> )	(km <sup>2</sup> )	
Strait of Juan de Fuca	Discovery Bay	Snow Creek	--	--	50	--	18, 19
		Salmon Creek	49	--	--	--	
	Sequim Bay	Jimmycomelately Creek	--	--	--	--	
		Dean Creek	--	--	--	--	
	New Dungeness Bay	Dungeness River	513	350	195	7	
	Fresh Water Bay	Elwha River	813	1340	1180	--	
	Lyre River	Lyre River	171	--	--	--	
	Pysht River	Pysht River	115	--	--	--	
	Clallam Bay	Clallam River	82	--	--	--	
	Hoko River	Hoko River	113	--	3620	--	
North Coastal	Sekiu River	Sekiu River	85	--	--	--	
	Sail River	Sail River	14	--	20	--	
	Mukkaw Bay	Waatch River	33	--	35	--	20, 21
		Sooes River	106	--	95	--	
	Ozette River	Ozette Lake/River	229	--	45	--	
	Quillayute River	Quillayute River	1629	--	--	--	
	Goodman Creek	Goodman Creek	82	--	--	--	
	Hoh River	Hoh River	774	2240	1300	--	
	Kalaloch Creek	Kalaloch Creek	--	--	--	--	
	Queets River	Queets River	1153	3690	3690	--	
Grays Harbor	Raft River	Raft River	197	--	490	--	
	Quinalt River	Lake Quinalt, Quinalt River	1124	2520	1420	--	
	Moclips River	Moclips River	91	--	120	--	
	Copalis River	Copalis River	--	--	--	--	
	Grays Harbor	Humptulips River	337	1190	935	--	22
		Hoquiam River	234	--	--	--	
		Wishkah River	117	--	--	136	
		Chehalis River	5358	6670	1570	--	
		Johns River	81	--	--	--	
		Elk River	47	--	--	--	
Willapa Bay	Willapa Bay	Cedar River	33	--	--	--	23
		North River	827	860	990	--	
		Willapa River	668	590	325	--	
		Niawiakum River	--	--	--	--	
		Palix River	95	--	--	167	
		North Nema River	56	105	55	--	
		South Nema River	47	--	65	--	
		Naselle River	142	385	315	--	
		Bear River	60	--	21	--	

-- = no data available.

n.a. = not applicable

<sup>1/</sup> Combined subaerial and littoral wetlands.

<sup>2/</sup> See Williams and others (1975) for description of water-inventory areas.

The volume of logs rafted in the Cowlitz River (fig. 7a) reflects log drives and the pattern of Washington's annual timber harvest until the depression in 1929. Since WWII, the use of the Cowlitz to transport or store logs has dropped to nothing, because of dry sorting and increased use of long truck hauls directly to the mill. The log activity in the Lewis River (fig. 7b) represents the era of log drives and river booming from 1900 to 1920. The big increase in rafted logs since 1957 represents storage for a pulp and paper mill at St. Helens,

across the Columbia River in Oregon. About 40 million board feet per year are rafted in and out of the first 6.4 km of the Lewis River. Grays Harbor (fig. 7c) totally reflects the annual Washington log-production curve until the 1940's, when the old-growth timber was gone and the second-growth timber was not yet being harvested. In the mid-1970's, major changes to dry-land sorting and environmental regulations drastically reduced the number of logs rafted in the bay feeding the two pulp mills. For 40 years, between 1920 and 1960, the volume of logs in general was



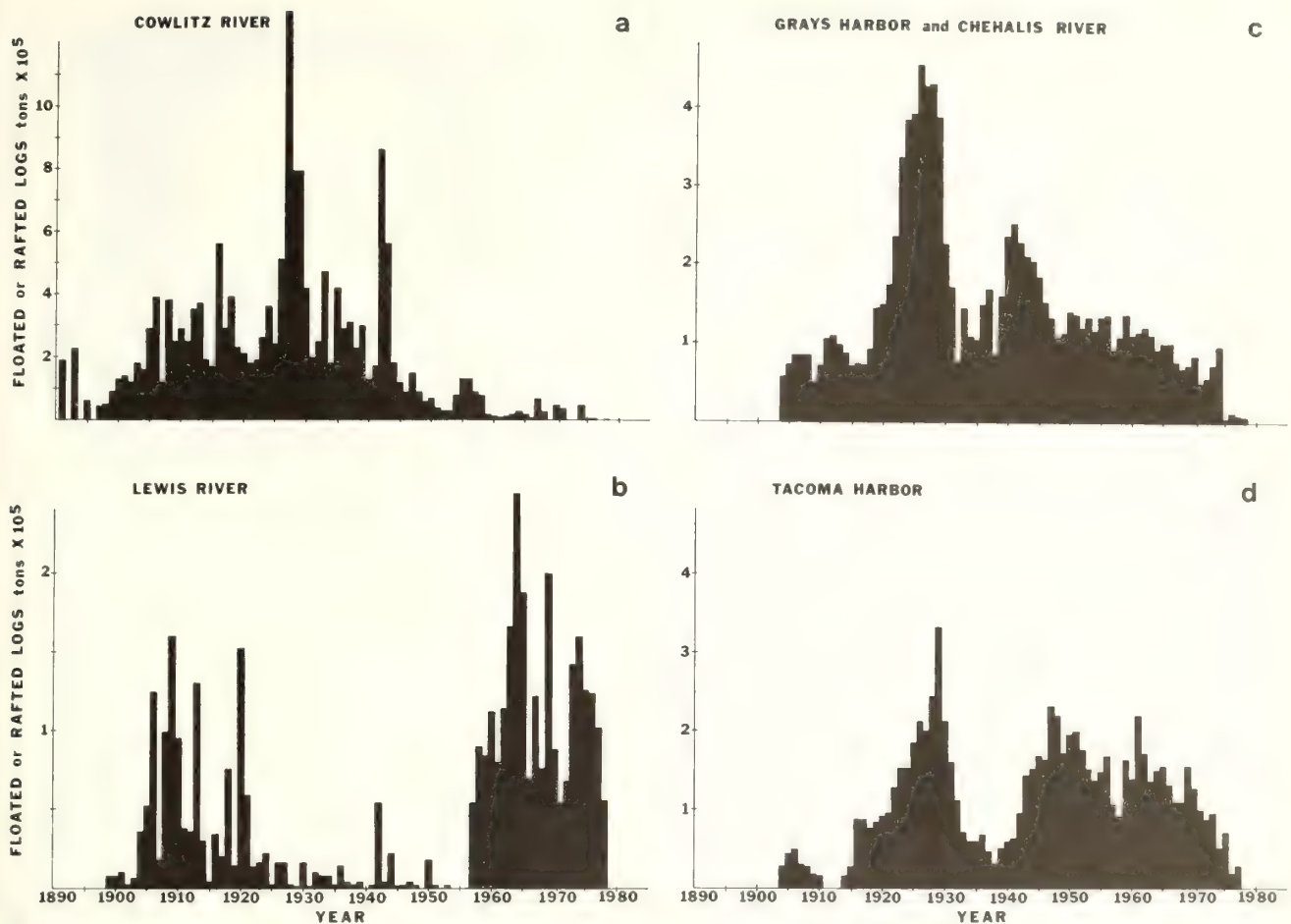


Figure 7.--Amount of logs floated on Washington rivers, a. Cowlitz River, 1890-1978; b. Lewis River, 1899-1978; c. Grays Harbor and Chehalis River, 1904-1978; d. Tacoma Harbor, 1904-1978.

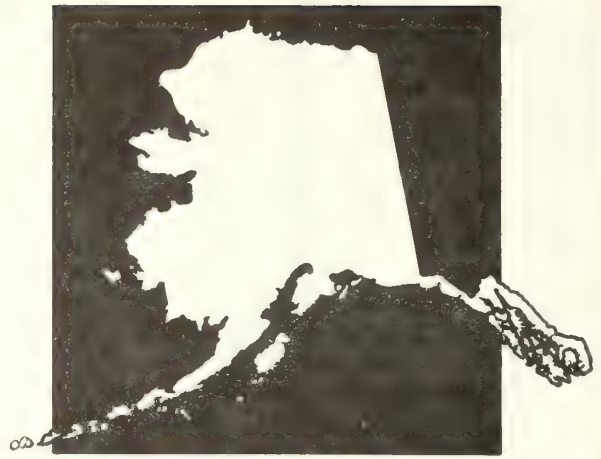
1/2 billion board feet annually. Tacoma Harbor (fig. 7d) also averaged 400 million board feet per year. Lake Washington, in Seattle, became a major route for rafted logs to Puget Sound mills when the Montlake Ship Canal was completed in 1916. Billions of board feet of logs were towed across the lake and through the canal. Presently, over 100 million board feet per year still traverse the lake and ship canal.

In the early days, 100 percent of the logs were transported by water. Grogan (1924) estimated that 60 percent of the logs that supplied the sawmills on Puget Sound and the Columbia River were transported either all or most of the way from the woods to the mill by water (about 5 billion board feet). Towing distances were between 160 and 320 km and the rafts were flat, not bundled; hence, many logs were lost, although in those days only prime Douglas-fir and western redcedar were used.



BRITISH COLUMBIA

The coastal harvest of British Columbia timber is greater than 7 billion board feet annually (Ainscough 1979). The most economical means of transporting logs from the forests to the mills is by marine waterways, large interior lakes, and the Fraser River system. Boyd (1979) and Cottel (1977) estimated that about 90 percent of the coastal timber harvest is placed in the water during part of its transportation to processing areas. Boyd (1979) has documented regional differences in the production, species, and modes of log transport within the coastal British Columbia forest industry during 1978.



ALASKA

Alaska, like British Columbia, totally depends on water to move logs to four major processing centers: Wrangell, Petersburg, Sitka, and Ketchikan. The number of estuaries in Alaska has been reported as between 1,000 and 22,000, depending on how "estuary" is defined. Obtaining an accurate number is difficult because of the large glacial bays (fjords), with numerous tributaries entering them (Faris and Vaughan 1985). Some people consider each tributary an estuary; others would use the term for the whole bay. In 1976, John Blankenship of the U.S. Fish and Wildlife Service calculated the area of all estuaries 40.5 ha or larger for the Tongass National Forest (table 11). The areas were planimetered from 1-inch-to-the-mile topographic maps. The total area of each estuary, and the area within each estuary that was 18 m or less in depth, were recorded. The areas were summed to obtain total estuarine area and shallow estuarine area (Faris and Vaughan 1985). Glacier Bay, upper Lynn Canal, and Annette Island were not included in the measurements because they are not part of the Tongass National Forest.

Table 11--Total estuarine area for Tongass National Forest, southeastern Alaska

Area	Total estuarine area	Estuarine area less than 18 m deep	Area less than 18 m deep
	Hectares	Hectares	Percent
Chatham	326 854	126 383	39
Stikine	137 441	91 157	66
Ketchikan	172 462	79 907	46
Total	636 757	297 447	47

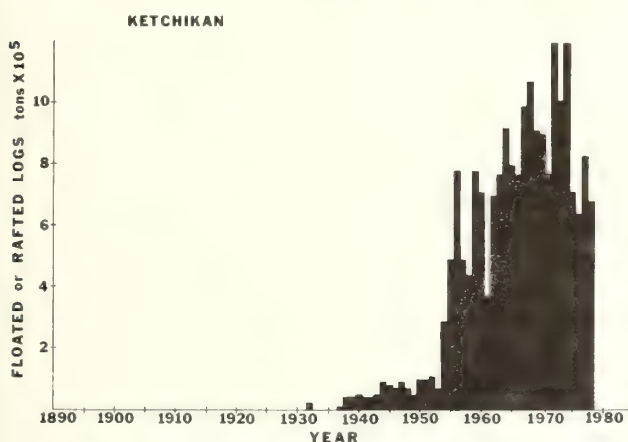
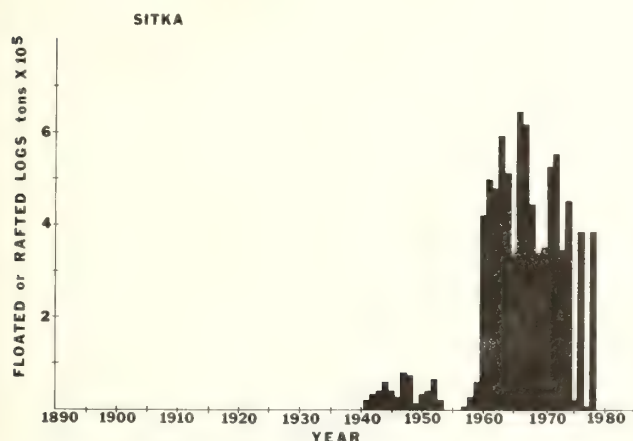
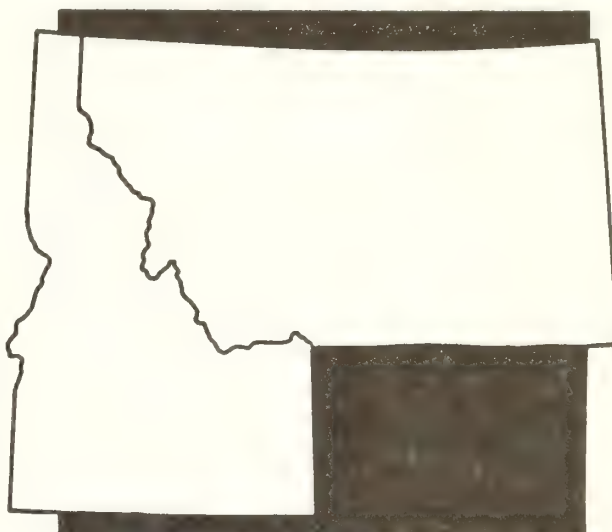


Figure 8.--Amount of logs floated or rafted to Sitka, 1940-1978, and Ketchikan, 1932-1978, Alaska.

Logs rafted to the Ketchikan and Sitka pulp mills are shown in figure 8. Not much logging was done until pulp mills opened in Ketchikan in 1954 and in Sitka in 1959. Since these openings, Ketchikan has annually received 200 to 300 million board feet of logs and Sitka has averaged slightly more than 100 million board feet annually. The total Alaska timber harvest peaked at 570

million board feet in 1970 and will probably not exceed 750 to 900 million board feet per year in the best of times. Its total estuarine area exceeds the estuary area of British Columbia because of the numerous islands.



IDAHO AND MONTANA

Large numbers of logs have been and continue to be rafted down the St. Joe River, across Coeur d'Alene Lake, and down part of the Spokane River (fig. 9). Log volumes peaked in the 1920's and since then have sustained an annual rafted volume of about 100 million board feet. Lakes and rivers that received the transported logs in the past are: Flathead Lake, Montana (fig. 9a); Coeur d'Alene Lake and St. Joe River (fig. 9b); Pend Oreille River, between Priest River, Idaho, and Ione (fig. 9c); and Priest River (fig. 9d). Peak activity for all but Flathead Lake was in the 1920's. Flathead Lake mills served mines and railroads between 1905 and 1920.



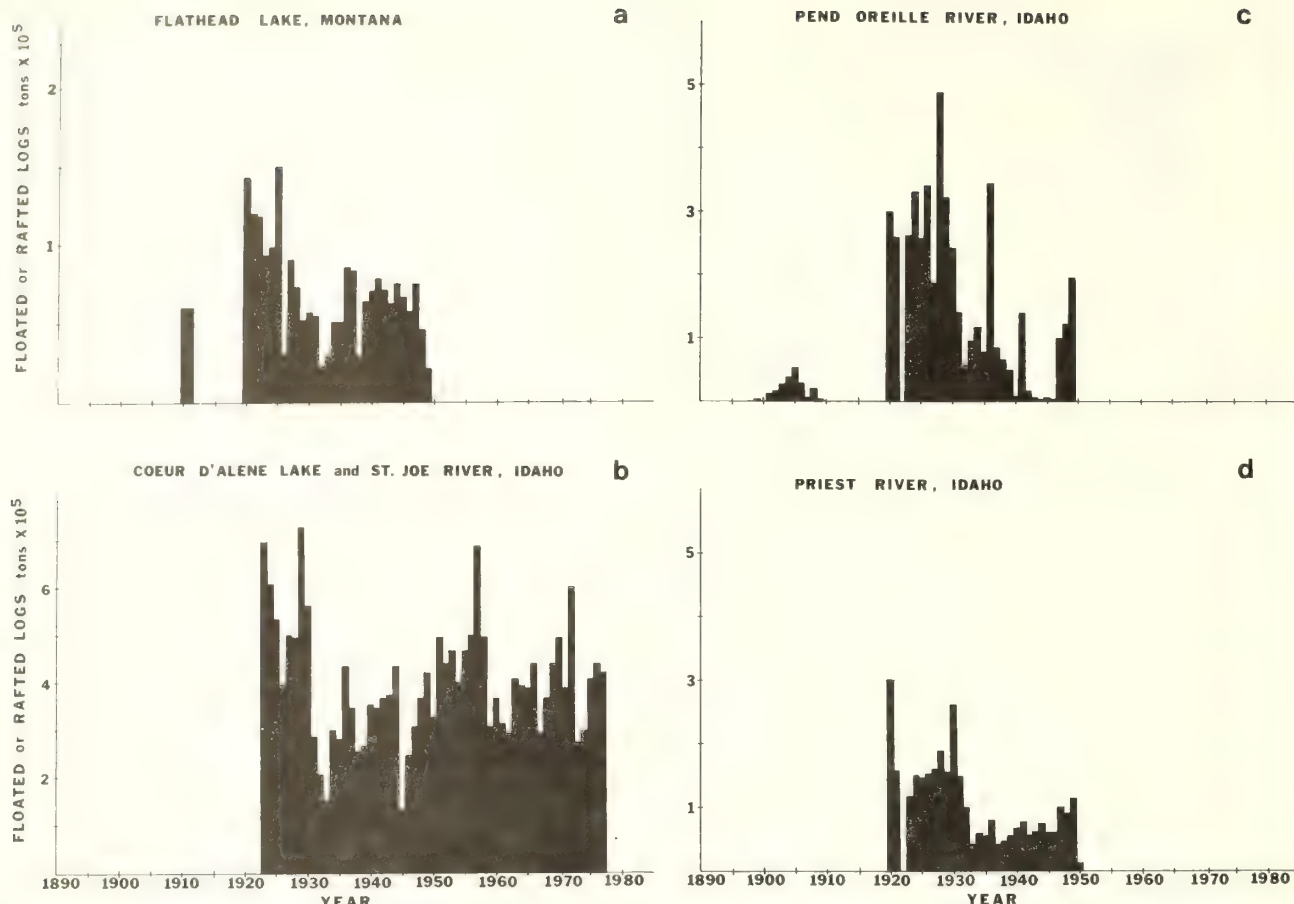


Figure 9.--Amount of logs floated or rafted on Montana and Idaho waters, a. Flathead Lake, Montana, 1910-1949; b. Coeur D'Alene Lake and St. Joe River, Idaho, 1920-1950; c. Pend Oreille River, Idaho, 1920-1949; d. Priest River, Idaho, 1920-1950.



## CALIFORNIA

California's waterways have carried logs for two centuries. Many streams in the redwood forests of Santa Cruz, Del Norte, Mendocino, and Humboldt counties experienced many log drives. The Sacramento River floated millions of board feet to mills located along its length. The records are almost nonexistent for volumes of logs handled in California estuaries. The principal estuaries used were San Francisco Bay, Los Angeles Harbor, and San Diego Harbor; they received hundreds of million board feet of logs shipped from Oregon and Washington. Humboldt Bay was too shallow to maintain a great volume of logs rafted in its waters, although it still rafts some logs near the mills. Most of California's bays are not located in timber country or are too small and rocky to have much log transportation.

# EXTENT OF LEASED LOG-STORAGE ACREAGE AND VOLUMES OF LOGS HANDLED

Leased acreages for Oregon total 794 ha. Of this, 41 percent are in coastal estuaries and the remaining 59 percent are primarily on the Columbia and Willamette Rivers (table 12). In Washington, 934 ha are leased to log handling, of which 85 percent are in estuaries (table 13).

Table 12--Total area of log-handling leases for Oregon

Waterways	Area	Portion of total area
	Hectares	Percent
<u>Coastal:</u>		
Necanicum River	0.08	
Salmon River	.28	
Siletz River	.97	
Yaquina Bay	16.81	
Yaquina River	30.33	
Siustlaw River	30.94	
Woahink Lake	2.03	
Siltcoos Lake	1.62	
Tahkenitch Lake	.41	
Smith River	3.77	
Umpqua River	104.65	
Umpqua and Smith Rivers	7.78	
Clear Lake	.04	
Coos Bay	21.87	
Coos River	324.0	
Isthmus Slough	58.56	
Coquille River	2.11	
Chetco River	.41	
Lake Ewanna	15.35	
Pacific Creek	.65	
Scholfield Creek	.30	
	622.96	59
<u>Columbia and Multnomah Channel:</u>		
Columbia River	170.0	
Westport Slough	.2	
Skipanon Slough	12.7	
Lewis and Clark River	.7	
Scapoose Bay	1.66	
Multnomah Channel	128.3	
Oregon Slough	38.1	
Sandy River	--	
	351.66	33
<u>Willamette:</u>		
Willamette River	56.9	
Tualatin River	--	
	56.9	5
<u>Inland:</u>		
Upper Klamath Lake	1.5	
Klamath Lake	.6	
Klamath River	4.5	
John Day River	.5	
Snake River	23.1	
	30.2	3
<b>Grand total</b>	<b>1061.7</b>	<b>100</b>

-- = no data available.

Table 13--Total area of log-handling leases for Washington

Waterways	Area	Portion of total area
	Hectares	Percent
<u>Coastal Washington:</u>		
Willapa Bay and River	15	
Grays Harbor and Chehalis River	120	
	135	14
<u>Puget Sound:</u>		
Anacortes		
Skagit Bay and River	141	
Seattle		
Snohomish	11	
Dabob Bay	34	
Port Angeles	109	
Tacoma Harbor,		
Puyallup River	45	
Kitsap area	33	
Skokomish River (Hood Canal)	58	
San Juan Islands	9	
Olympia Harbor	100	
	540	58
<u>Columbia River:</u>		
Gray's Bay		
Columbia Estuary	61	
Kelso/Longview		
Columbia River		
Cowlitz River (mouth)	145	
Lewis River; Vancouver,		
Washington	1	
Lower Columbia River	47	
Lower Columbia River		
Klickitat River	5	
	259	28
<b>Grand total</b>	<b>934</b>	<b>100</b>

British Columbia has 8956 ha under lease (table 14). A survey of 943 log-handling leases by FERIC (1980) indicated that the majority of British Columbia water leases are located in coastal rivers (29.0 percent), intertidal areas (22.1 percent), and deep-water environments (31.1 percent), although log-handling sites in estuaries tend to be larger than other leased areas because most processing sites are located there (table 14). Ainscough (1979) documented the locations of major log-sorting, dumping, booming, and processing sites along the south coast of British Columbia (fig. 10).

Table 14--Location and average size of coastal British Columbia log-handling leases<sup>1/</sup> (FERIC 1980)

Location	Area	Portion of total leases	Average area
	Hectares	Percent	Hectares
Lake <sup>2/</sup>	197.8	2.2	12.4
River <sup>3/</sup>	1,200.2	13.4	6.3
Estuary	954.6	10.7	25.1
Intertidal	2,259.1	25.2	15.5
Deep water	2,997.0	33.5	14.5
River/estuary	50.9	0.6	25.5
Estuary/intertidal	164.3	1.8	16.4
Intertidal/deep water	1,083.5	12.1	22.6
Other combinations	48.8	.5	12.2
Total	8,956.2	100.0	

<sup>1/</sup> Based on a questionnaire survey of 187 companies with 943 leases; 66-percent response of B.C. coastal forest industry.

<sup>2/</sup> Pitt and Harrison Lakes.

<sup>3/</sup> Fraser River constitutes 98 percent of this use.

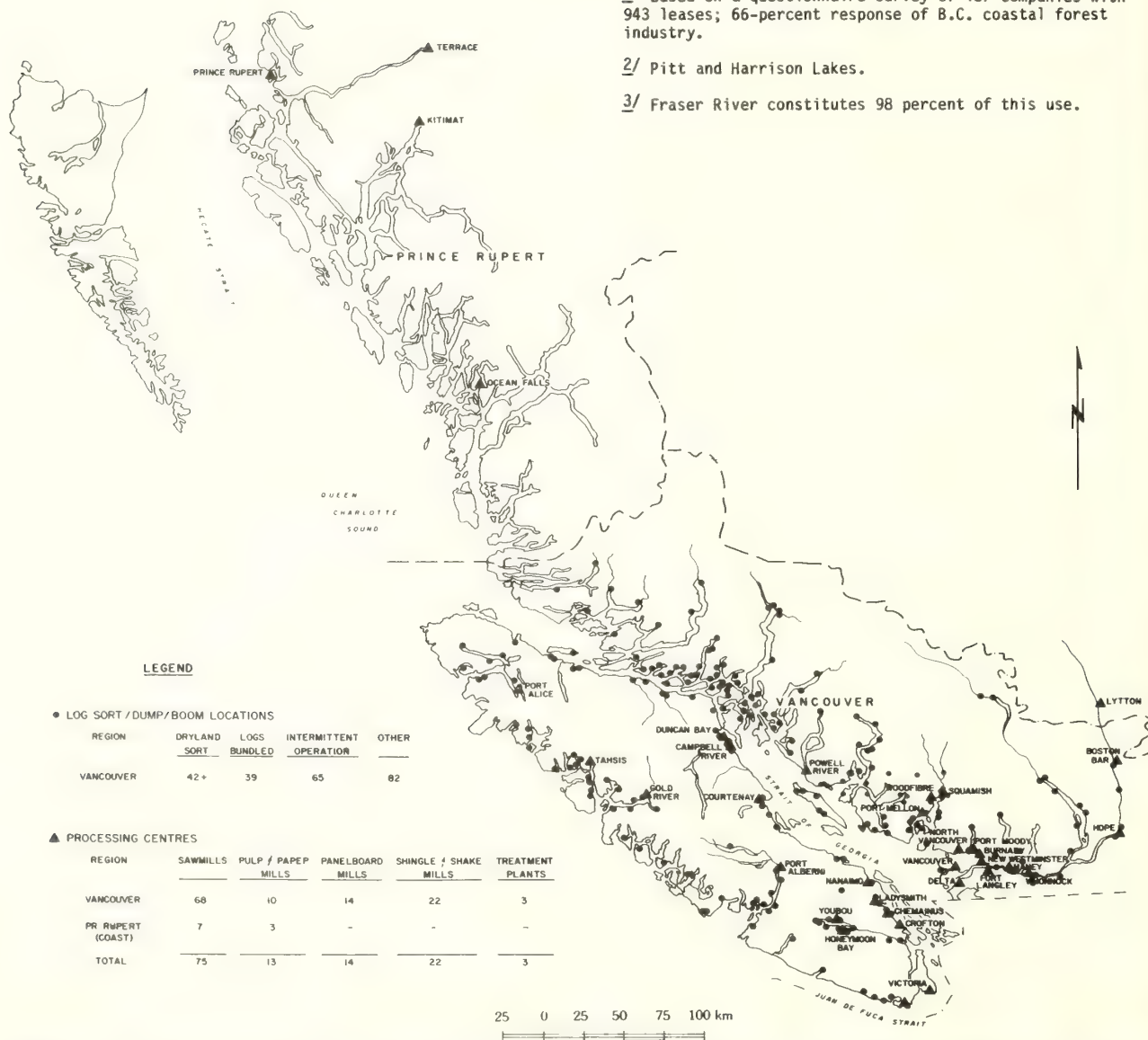


Figure 10.--Log sorting, dumping, booming, and processing locations along the south coast of British Columbia.



The FERIC (1980) report indicated that the greatest proportion of log-handling water leases in coastal British Columbia were used for log storage, with relatively minor areas used for dumping, and to a lesser extent sorting (table 15). The information reported in this study has been considered representative of present Canadian coastal log-handling practices.

Alaska has 430 ha under lease, representing 89 log-transfer sites and 49 log-storage sites. Another 228 sites are proposed for log-transfer facilities and 12 sites are proposed for log storage (Faris and Vaughan 1985). Faris and Vaughan (1985) constructed a map showing processing plants; abandoned, new, and proposed dump sites; and abandoned, currently occupied, and proposed storage sites (fig. 11). They estimated that 0.01 percent of the total estuarine area is affected by bark accumulation adjacent to the log-transfer facilities and project that a worst case for the future would represent 0.04 percent of the estuarine total. Volumes of logs moved are not great in Alaska when compared with log-handling activity in British Columbia, Washington, and Oregon.

Table 15--Major uses of coastal British Columbia log-handling leases<sup>1/</sup> (FERIC 1980)

Use	Area	Portion of area
	Hectares	Percent
Log dumping	204.2	2.3
Barge dumping	132.6	1.5
Barge loading	205.6	2.3
Log sorting/booming	1,312.0	14.7
Log bundling	86.0	1.0
Log storage	5,696.1	63.6
No present use	796.4	8.9
Other	522.9	5.8
Total	8,955.8	100.0

<sup>1/</sup> Based on a questionnaire survey of 187 companies with 943 leases; 66-percent response of B.C. coastal forest industry.

Herrmann (1979) has calculated the effects of log-rafting sites on benthic invertebrates and fish production in the entire Coos Bay, Oregon, estuary. He estimated summer benthic invertebrate biomass of 85 ha of intertidal log-storage areas to be 2050 kg (dry weight). This was compared to his estimate of 64 370 kg and 257 000 kg for the benthos on the upper bay and entire Coos Bay tideflats, respectively. He further stated that the 2050 kg of benthos could produce about 1370 kg (live weight) of fish tissue. This amounted to about 0.6 percent of his estimated fish production of the entire Coos Bay tideflats (Herrmann 1979).

When the activity per hectare leased is compared to total estuary available (table 16), log handling--although occupying sensitive intertidal zones--impinges on less than one tenth of one percent of the estuary area available. Guidelines are in effect to minimize the impacts by limiting site location. Log transportation directly affects estuaries in British Columbia much more than in Alaska, Washington, and Oregon. British Columbia has also spent more money and time analyzing and researching the problem than has any other area.

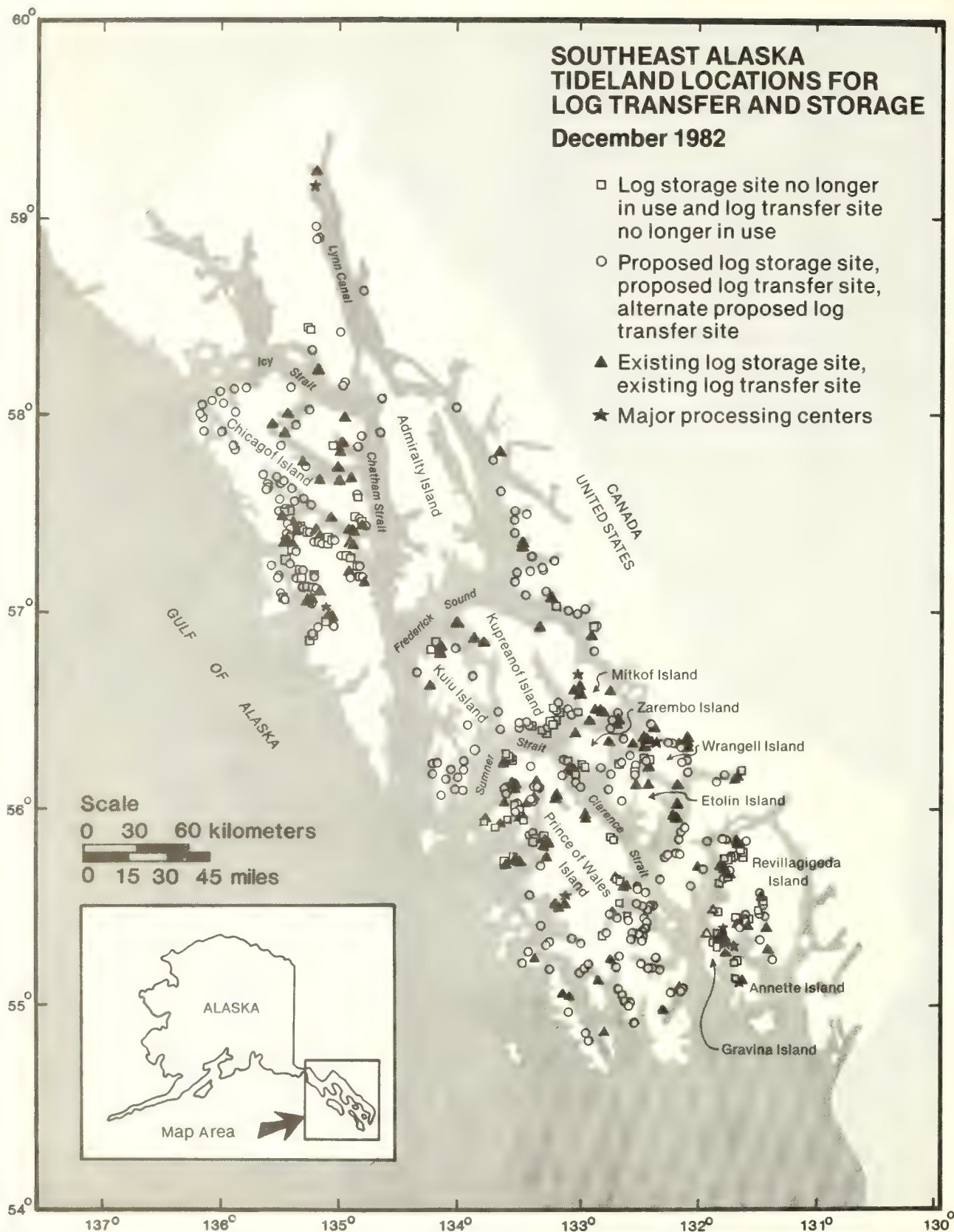


Figure 11.--Tideland locations for log transfer and storage, southeast Alaska, 1982.  
From Faris and Vaughan (1985).

Table 16--Comparison by State and Province of log-handling leases, area affected, and board feet of logs transported

State/Province	Number of sites leased	Number of hectares leased	Estimated board feet of logs transported or stored X 10 <sup>6</sup>
Southeastern Alaska	81	430	400
British Columbia	943	8956	6,030
Washington	154	943	4,000
Oregon	100	794	3,500

Although data show that only a small fraction of the total available estuarine area might be affected, a strong rationale remains to attempt to locate that fraction on the least damageable portion of the available estuary. The fact that only a small amount of total estuarine area may be involved in log-transfer activities should not be used as an excuse to avoid the responsibility of minimizing or reasonably mitigating damages at individual sites. Faris and Vaughan's (1985) conclusion underscores the fact that available data are just now providing some understanding about the role of certain areas of the estuary in salmon production. Even though a large proportion of the original marshlands and intertidal areas have been lost in California, Oregon, Washington, and British Columbia, how this has affected salmon runs is impossible to say. We do not know whether the amount of intertidal and marsh area is approaching some lower limit critical to the survival of the present salmon production. All along the western Pacific coast, from California to central Alaska, major investments are being made to enhance salmon runs, and we do not know whether the intertidal estuaries and marshes are adequate or needed to support the increased numbers. Clearly, the consequences of allowing estuarine areas to be destroyed are highly uncertain and could put valuable salmon runs in jeopardy. This uncertainty about the importance of estuarine areas to salmon is likely to persist in the immediate future, despite the best research efforts. The estuarine and marsh areas and the salmon systems

associated with them are complex and large. Added to this is the relatively long life cycle of the salmon, taking as many as four or more years before the adult returns through the estuary. These characteristics make the research task difficult, lengthy, and costly. Currently, our technology and organization of research is poorly developed to meet the challenge.

Planning for log transportation--whether floating or land-to-barge systems--as well as for other competing developments, must consider this continuing uncertainty. Guidelines for ecological-impact assessment must be designed so that the information required reflects what can reasonably be developed in a short time and does not falsely imply that impacts on salmon can be measured in a short time.

## INFORMATION GAPS AND RESEARCH RECOMMENDATIONS

An extensive amount of information is available on certain aspects of log handling and storage. Most studies have concentrated on bark loss, benthic habitat alteration, benthic organisms, leachates, and grounding effects. This information has been used to establish corrective regulations and policies. Most fisheries biologists, ecologists, environmentalists, and conservationists--as well as much of the public--would answer yes to the question: "Is log transfer and storage detrimental to the estuary and salmonid species?" Most believe that estuaries are essential





components to survival of salmon stocks of the Pacific Northwest and that any disturbance to the estuary is detrimental, no matter how small the area affected.

From our review of the literature, we conclude that evidence is inconclusive on the importance of the small areas impacted by log transfer and storage to overall production and population success of bivalves, crabs, or salmonids. Log-transfer sites and estuarine ecosystems vary greatly and, with the present status of knowledge, evidence from one estuary must be applied with great care to another.

Information gaps exist; for example, knowledge is inadequate on the availability and the quality of alternative habitats for salmonids and other species. Such information is essential to evaluate the importance of present and proposed log-transfer and storage sites to the species of interest. Would organisms--fish, for example--congregate in the remaining log-transfer site in an estuary or would they occupy other estuarine or coastal habitats? In those alternative habitats, would fish have comparable survival rates, or would their survival be poorer? The same questions need to be answered for crabs and mollusks.

Dry-land alternatives to freshwater or marine log transfer and storage may present irreversible alterations to upland habitats or permanent structures that can displace the marine habitat with pilings and rock fill. On-shore storage and handling of logs, although protecting the marine habitat, can permanently change the shoreline and present a different set of bark-disposal problems (Forest Engineering Incorporated 1982).

Avifauna and marine mammals use log rafts as feeding and resting stations, and as nesting spots. Older rafts in fresh water with brush growing on them may be used for breeding and nesting. Both the avifauna and marine mammals are significant components of the ecosystem; the relation between these organisms and log rafts, including consequences of raft removal, should be studied. The incidence of usage of log rafts by mammals should be determined.

Except for cursory observations, the significance of using log rafts as habitat or protective cover by fish has not been well documented. We need to determine whether storage and dumping areas provide significant habitat for fish, or if certain species avoid the rafts because of leachates or other factors. Studies could be limited to determining whether fish abundance and distribution are influenced by the rafts and dumping activities. Emphasis should be placed on sloughs and backwater areas where flushing action is minimal and where leachate concentrations are expected to be greatest.

When sunken logs are retrieved, the benthic habitat is disturbed. Maintenance dredging of log-dumping areas, and the disturbance of bottom sediments by tugs and other log-handling vessels may cause similar effects. The significance of this disruption has not been documented or quantified. Because of the potential for negative impact (such as resuspension of toxic materials or damage to benthic habitat) compared to

the positive impact of retrieving salvageable logs, an examination should be made of the extent of area affected by retrieval operations, maintenance dredging, and the activities of vessels in log-handling areas.

In general, less emphasis should be placed on studying impacts that have already been described, because regulations are in effect or are being developed to alleviate them. Both positive and negative impacts not previously studied should be given more emphasis, particularly relative to their effect on the whole ecosystem. Research priority should be given to areas of poor water circulation, because effects would be greatest in these areas.

## RECOMMENDED PRACTICES

The following protective measures, based on a Task Force Report on Log Storage and Rafting in Public Waters (Hansen and others 1971) (approved by the Pacific Northwest Pollution Control Council), were designed to minimize the impacts of log handling on the aquatic environment; they are still applicable today:

- Dry-land handling and sorting is preferred to water handling and sorting, although the location of dry-land facilities should not be in fisheries-sensitive zones, such as estuaries, salt marshes, herring spawning areas, or shellfish beds.
- The free-fall, violent dumping of logs into water should be prohibited, because this is the major cause and point source of loose bark and other log debris.
- Easy let-down devices should be used to place logs in the water, thereby reducing bark separation and generation of other wood debris.

- Positive bark and wood-debris controls, collection, and disposal methods should be used at log dumps, raft-building areas, and millside handling zones for both floating and sinking particles.
- Log dumps should not be located in rapidly flowing waters or other zones where positive bark and debris controls cannot be effective.
- Accumulations of bark and other debris on the land and docks around dump sites should be kept out of the water.
- Whenever possible, logs should not be dumped, stored, or rafted where grounding, particularly on sensitive habitats, will occur.
- Where water depths will permit the floating of bundled logs, they should be secured in bundles on land before being placed in the water. Bundles should not be broken again except on land or at millside.
- The inventory of logs in water for any purpose should be kept to the lowest possible number for the shortest possible time.

More site-specific measures can be applied to a particular operation to ensure protection of aquatic habitat (Toews and Brownlee 1981), based on the specific resources present and the details of the operation. A technical assessment of a log-handling proposal might therefore include the following considerations:

- Site sensitivity and uniqueness

Resource values present (for example, shellfish, herring spawn, emergent vegetation, salmonid rearing).

Physical characteristics of site (for example, substrate, depth, currents, tidal flushing).

Dumping, sorting, transport methods.

Log volumes and inventory, seasonal log flow.

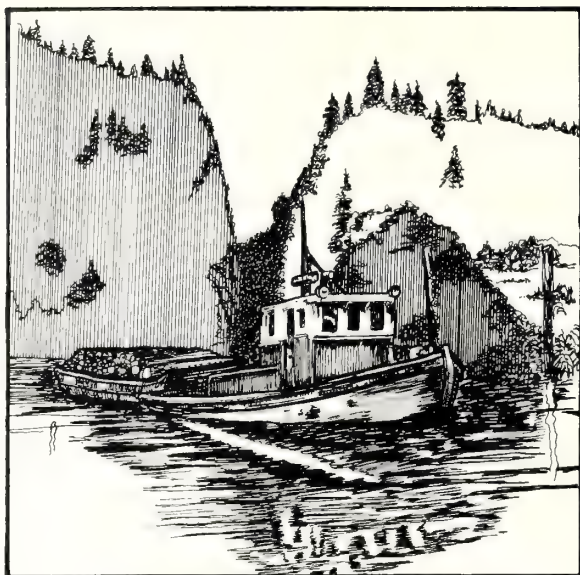
Duration of operation (usually related to upland logging).

Positive debris-control measures (recovery and disposal of both floating and sinking debris).

- Potential impacts based on above considerations for both proposed and alternate sites (alternate sites may include those on dry land).

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# APPENDIX

Total timber produced (thousand board feet) in the western United States, 1869-1946

Year	Oregon	Washington	California	Idaho	Montana
1869	75,193	128,743	3,530,842	1,490	12,571
1879	177,171	160,176	326,340	18,204	24,420
1889	462,620	1,160,023	528,554	30,933	93,314
1899	734,538	1,429,032	737,760	65,363	255,685
1904	987,107	2,485,628	1,088,788	211,447	236,430
1905	1,262,610	3,917,166	1,061,608	212,725	189,291
1906	1,604,894	4,305,053	1,348,359	418,944	328,727
1907	1,635,563	3,777,606	1,350,887	513,788	343,814
1908	1,468,158	2,915,928	1,005,515	518,625	311,533
1909	1,898,985	3,862,916	1,154,007	645,800	308,582
1910	2,084,633	4,397,492	1,265,876	745,984	319,089
1911	1,803,698	4,064,754	1,218,838	765,670	228,416
1912	1,916,160	4,099,775	1,223,259	713,575	272,174
1913	2,098,467	4,592,053	1,201,957	652,616	357,974
1914	1,817,875	3,946,189	1,318,065	763,508	317,842
1915	1,505,633	3,726,343	1,119,458	770,031	324,333
1916	2,221,854	4,492,997	1,413,541	846,107	383,884
1917	2,485,783	4,304,449	1,417,068	749,764	347,496
1918	2,708,955	4,602,469	1,277,084	802,529	335,811
1919	2,577,403	4,961,220	1,279,698	765,388	287,378
1920	3,316,098	5,524,509	1,482,102	969,576	409,667
1921	2,022,219	3,831,800	1,360,514	542,620	216,989
1922	3,023,768	5,836,277	1,720,556	857,581	303,458
1923	3,966,083	6,677,656	2,118,094	1,072,930	426,917
1924	3,665,547	6,267,343	1,996,496	1,017,960	350,335
1925	4,216,383	7,027,325	2,042,991	1,140,575	388,854
1926	4,454,735	7,546,239	2,187,959	947,471	378,698
1927	3,972,852	7,325,862	2,070,811	823,986	396,267
1928	4,371,924	7,305,277	1,952,654	977,468	387,879
1929	4,784,009	7,302,063	2,063,229	1,028,791	388,711
1930	3,654,075	5,502,129	1,514,263	840,409	296,990
1931	2,628,358	3,917,997	957,740	499,899	158,213
1932	1,603,892	2,260,689	680,520	248,378	111,048
1933	2,256,028	3,106,095	784,626	316,471	125,126
1934	2,379,642	3,064,270	1,014,447	457,089	171,841
1935	3,145,237	3,452,527	1,355,713	609,212	233,633
1936	4,077,424	4,572,397	1,647,537	723,804	295,233
1937	4,351,723	4,712,698	1,775,734	797,492	335,045
1938	3,790,896	3,348,567	1,461,964	570,571	221,579
1939	4,764,804	4,244,001	1,684,644	675,165	271,096
1940	5,202,111	4,541,702	1,954,500	773,650	325,338
1941	6,346,470	5,239,713	2,331,893	912,203	373,970
1942	6,480,178	4,976,170	2,330,041	930,368	433,089
1943	6,401,424	4,490,086	2,352,592	889,748	423,520
1944	6,322,259	4,349,914	2,468,943	910,545	448,498
1945	5,003,547	3,257,995	2,260,792	780,453	341,749
1946	6,328,317	3,422,289	2,681,173	863,964	413,859





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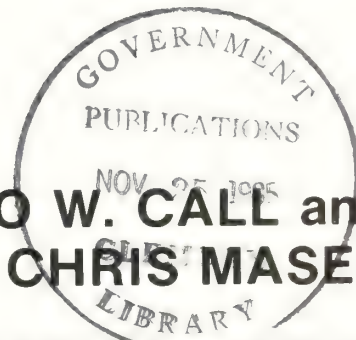
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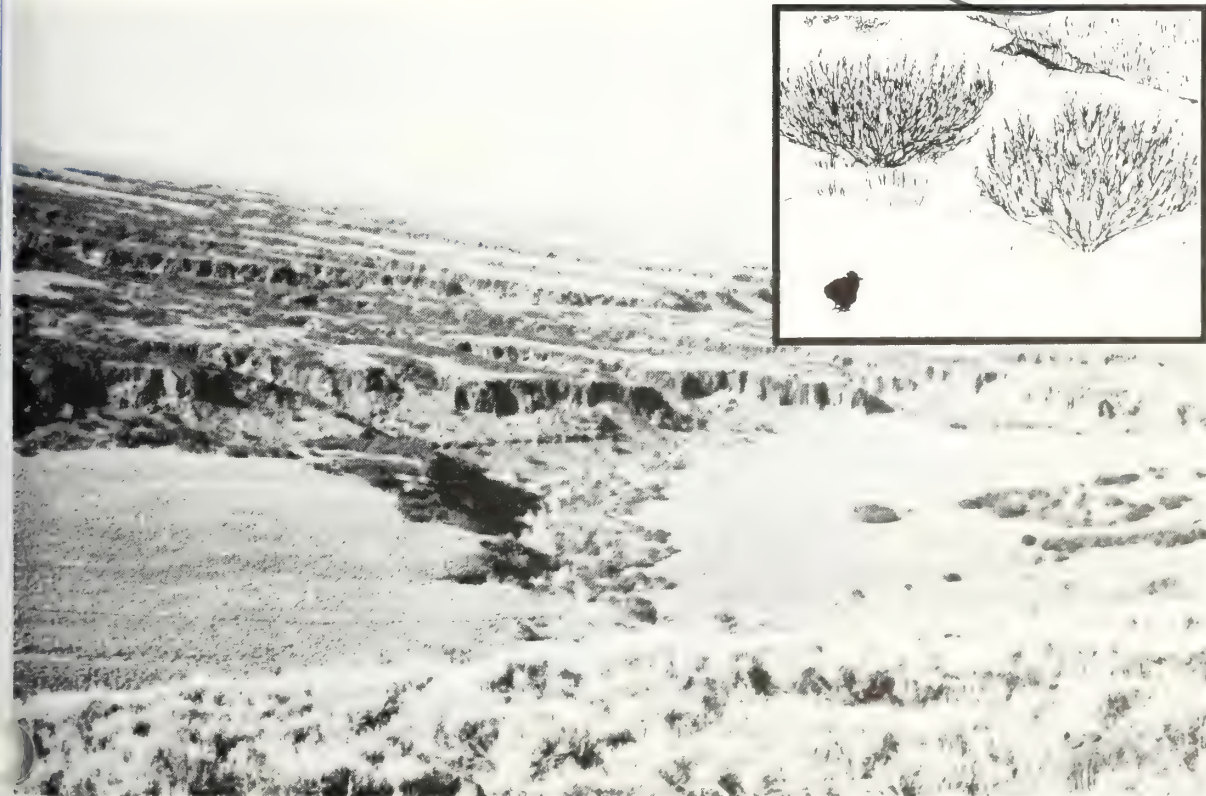
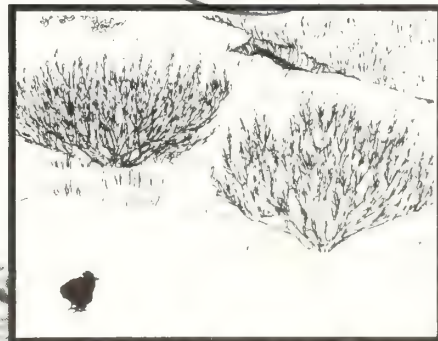


# WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASIN OF SOUTHEASTERN OREGON

## SAGE GROUSE



MAYO W. CALL and  
CHRIS MASER







## Introduction

The sage grouse<sup>1</sup> is one of the habitat-specific birds of the West. It relies primarily on one particular plant type—sagebrush—to meet its life requirements (Patterson 1952). Studies of the food habits of sage grouse throughout their range reveal dependence on sagebrush from October through April. In May, sage grouse shift to a diet dominated by forbs, and in September they go back to sagebrush (Bean 1941, Dargan et al. 1942, Girard 1937, Griner 1939, Klebenow and Gray 1968, Oakleaf 1971, Peterson 1970a, Wallestad et al. 1975).

Sage grouse occur throughout the range of big sagebrush, but their numbers are now reduced, and they have disappeared from peripheral areas where sagebrush has been extensively removed (U.S. Department of the Interior, Bureau of Land Management 1970) (figs. 1 and 2). A considerable reduction in numbers has occurred as a result of settlement, but they have been extirpated in British Columbia and maybe in Arizona (Patterson 1952). Both the eastern and western subspecies are found in the Great Basin in Oregon (Masson and Mace 1974).

The distribution of sage grouse is not continuous because of the interspersed forested mountainous areas. Historically, as today, sage grouse were commonly found near mountains. High plateaus and intermountain valleys provide the best conditions for survival of sage grouse (Patterson 1952).

Martin et al. (1951) estimated that more than 50 percent of the original sage grouse habitat had been eliminated. By 1967, 1.97-2.36 million ha (5-6 million acres) of rangelands had been treated to reduce sagebrush (Schneegas 1967). Hundreds of thousands of additional hectares (acres) have been modified since 1967. Sagebrush has been sprayed, plowed, chained, burned, disked, cut, or beaten to convert the land to grassland (fig. 3). Heavy grazing by domestic livestock, irrigation projects, dry land farming, seeding, and miscellaneous factors have played a part in altering original habitats (Rogers 1964).

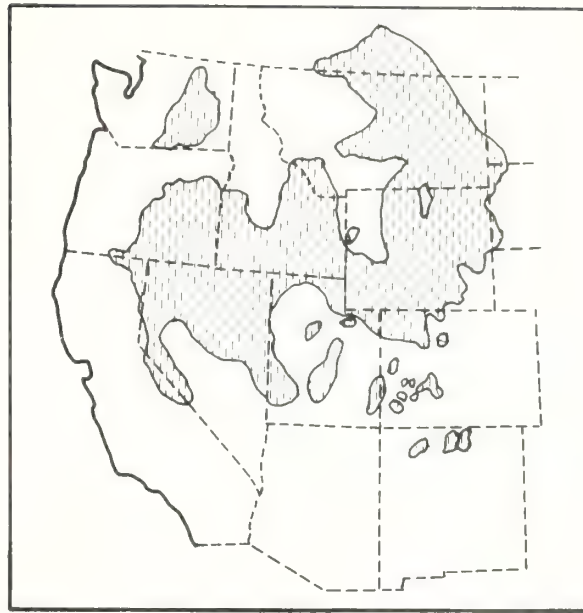


Figure 1.—Sage grouse distribution in North America in 1975 (after Wallestad 1975).

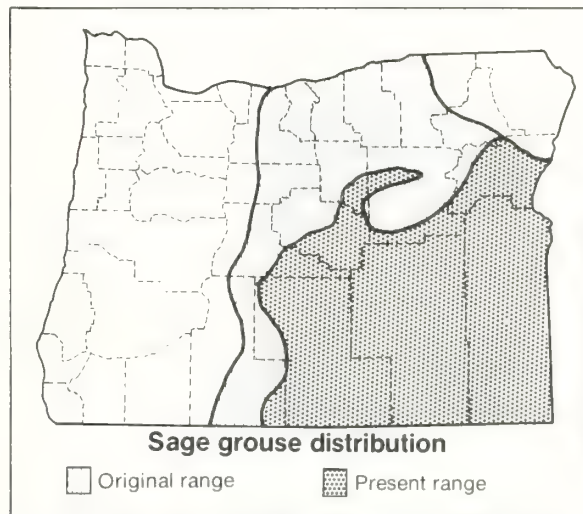


Figure 2.—Sage grouse distribution in Oregon in 1974 (after Masson and Mace 1974).

<sup>1</sup>Common and scientific names are listed in the appendix.



Figure 3.—Aerial spraying of herbicides has been one of the most common methods for killing sagebrush. Increased grass production for livestock results, but habitat for sage grouse may be eliminated.

Decreases in sage grouse followed the decrease in sagebrush. Other factors, such as unfavorable weather conditions at hatching time and increased predation, hunting, and disease have each been important at various times in localized areas but are probably not the most important factors in the overall downward trend.

The major factor that most adversely affects wildlife populations over the long term is the loss, in quality or quantity, of habitat (Call 1979). The number of sage grouse can be expected to decrease in areas where human populations and agricultural developments are expanding. In earlier years, habitat losses occurred primarily from the effects of heavy grazing by livestock or from programs that reduced sagebrush and increased grass production. More recently, habitat losses are occurring because of strip mining for coal, development of oil and gas fields, industrial developments, and related activities. The people required to operate the facilities often disturb surrounding lands so they are no longer suitable for grouse.

There has also been maximum exploitation of surface water for irrigation, mining, and other domestic purposes; entire streams have sometimes been diverted. In other instances the application of water to lands unsuitable for cultivation resulted in leaching of alkali salts that polluted stream courses and converted sagebrush lands into salt shrub areas (Patterson 1952).

Sage grouse suffered the same losses of habitat in Oregon as in other States. From 1934 through 1983, 157 198 ha (388,144 acres) of vegetation were treated to increase grass production in southeastern Oregon (U.S. Department of the Interior, Bureau of Land Management 1983). In addition, wildfires have altered large areas of sage grouse habitat, at least temporarily.

Sage grouse fluctuated considerably in different areas over the years.<sup>2</sup> The most important factors influencing productivity and survival are conjectural—predation, forb production, weather, hunting, and habitat changes.

Sage grouse have not adjusted, and probably will not adjust, their life processes to fit a pattern of land use that eliminates or adversely disturbs large tracts of sagebrush to which they are tied for food and nesting cover.

Fortunately, some changes resulting from livestock grazing, agricultural practices, and other land uses may have benefited sage grouse. The creation of openings in large sagebrush stands, from whatever causes, produced feeding and brooding areas and may have benefited sage grouse especially where water is close by. The creation of meadows (or meadowlike areas) within sagebrush stands improved the summer food supply of sage grouse. Where land use practices removed large, decadent sagebrush stands and permitted development of new, young plants, sage grouse habitat may have been improved. But the overall habitat is generally better where patches or strips of tall, dense sagebrush are retained for use as escape cover or for roosting.

<sup>2</sup>J. A. Crawford, Oregon State University, Corvallis, personal communication.



## Assumptions

In this chapter, we define cover and forage components of optimum sage grouse habitat and describe how changes in plant community structure and composition affect habitat quality. Optimum habitat for sage grouse may not always be maintained because of other resource needs and uses, but compromises to meet the needs of the grouse can be made. Our intent is to help rangeland managers evaluate impacts and trade-offs of habitat manipulations for sage grouse.

We have made these assumptions:

1. Eastern and western sage grouse subspecies in Oregon have similar habitat requirements and respond similarly to habitat alterations.
2. Where there are conflicts between sage grouse and livestock on public lands, it may be essential to give priority to sage grouse if they are to continue to exist on these areas.
3. Research results and management principles are applicable for sage grouse from other areas provided modifications are made to account for local circumstances.
4. Oregon has different subspecies or varieties of sagebrush than those found in some other Western States, so there may be differences in sage grouse use of various subspecies of sagebrush for food and

cover. Habitat management principles, however, remain essentially the same.

5. The needs of sage grouse will take precedence over livestock on important brood-rearing areas to ensure adequate food.
6. Land uses can be tailored to provide areas of sufficient size to maintain viable populations of sage grouse.

## Habitat Requirements

Sage grouse densities vary in the Great Basin of southeastern Oregon, depending on the subspecies and structure of the sagebrush, composition and density of the understory vegetation, intensity of livestock grazing, presence of water, and human disturbance. Some of the general habitat requirements of sage grouse on sagebrush-grasslands follow.

### ABIOTIC FACTORS

#### Topography

Although some forms of sagebrush grow on shallow, rocky soils found on ridges and sidehills, the most vigorous stands occur on the deeper soils of valleys and gently rolling terrain. Sage grouse depend primarily on sagebrush for cover, so most sage grouse are found in sagebrush habitats where slopes are less than 30 percent, although they are occasionally encountered on steeper slopes (fig. 4). Sage

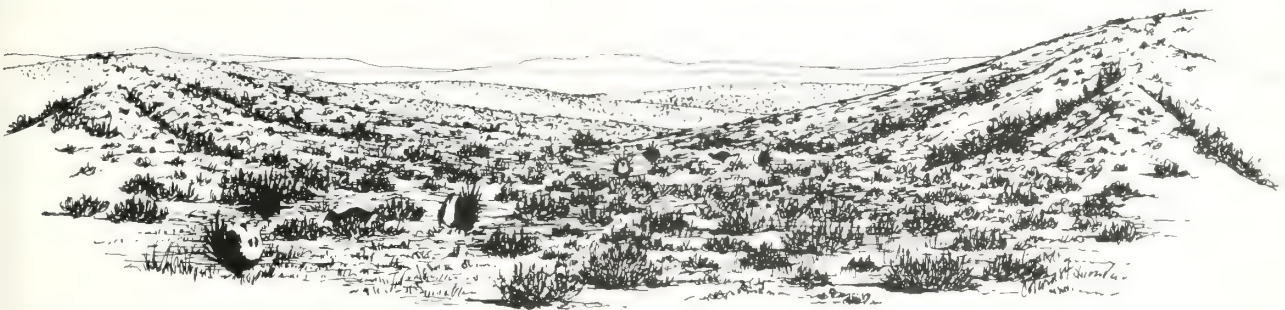


Figure 4.—Low, rolling hills and adjacent valleys provide the best topography and habitat for sage grouse, especially where patches of big sagebrush are intermixed with areas of low sagebrush. Sage grouse commonly move to higher elevations to find more succulent forbs as summer progresses.



grouse often follow the development of succulent forbs by moving from valleys to higher elevations during early summer (Batterson and Morse 1948, Nelson 1955, Patterson 1952). Exceptions to such movement occur. Batterson and Morse (1948) noted that migrations in Baker County, Oregon, for example, involved movement down to the valleys in summer, up to the hills in late fall, and down to the strutting grounds in late winter.

### Barriers to Movement

There are no known barriers that prevent the occupation of suitable habitat by sage grouse. If they are not found in good habitats, they likely have been extirpated.

### Elevation

The best populations of sage grouse in the Great Basin of southeastern Oregon are between elevations of 1220 and 2438 m (4,000 and 8,000 ft), although individuals and small groups may be found at lower elevations.<sup>3</sup>

### Climate

The highest densities of sage grouse occur where precipitation averages 25-38 cm (10-16 in) per year. Marginal populations occur in areas of lesser precipitation.

### Water

We believe that free water is an essential component of sage grouse habitat. The need for free water in summer, however, probably depends on: (1) the amount of available, preferred, succulent vegetation produced; and (2) how early in summer the preferred forbs dry out. Other authors (Autenrieth 1981, Girard 1935, Griner 1939, Savage 1969) also consider free water essential, but a few do not (Batterson and Morse 1948, Nelson 1955, Trueblood 1954). For instance, Griner (1939) stated that all of the 161 nests he found were within 0.8 km (0.5 mi) of water. Keller et al. (1941) reported no preference for slope, exposure, or nearness to water.

Patterson (1950) stated that nesting density was slightly higher on areas adjacent to main irrigation canals and creeks than on areas 1.6 to 3.2 km (1 to 2 mi) from running water. Girard (1935) found that sage grouse broods need water within a few hours after hatching and, consequently, move immediately to stream areas. Batterson and Morse (1948) raised a brood of chicks to 4 weeks without giving them free water, and without apparent ill effects. Trueblood (1954) believed that sage grouse chicks obtain most of their water from succulent vegetation and dew in years of above-average rainfall.

Nelson (1955) noted no connection between selection of nest site and the presence of water. The majority of the nests he observed were on sagebrush flats 1.6 to 4.8 km (1 to 3 mi) from the nearest permanent source of water. He stated, however, that spring rains and snows create many small standing pools in places with poor drainage, as well as in rock depressions. Consequently, there may be no need for sage grouse to move to permanent sources of water during most of the nesting period.

Migrating grouse gather around waterholes and in meadows along fall migration routes in Idaho. Although daily movements are modified by weather conditions, grouse often wait near waterholes until 0700 or 0800 h and then drink. Watering lasts 10 to 30 min (Dalke et al. 1963). Knowing that grouse use waterholes early in the morning in autumn, hunters frequently kill grouse at such places, especially where meadows are nearby.

Sage grouse regularly visited partially frozen streams in Eden Valley, Wyoming, in late fall to drink through holes in the ice. Ranchers told stories of flocks coming into their yards and drinking from livestock watering troughs (Patterson 1952).

Sage grouse may do well in the absence of free water where they have access to succulent vegetation. Moisture requirements are partially fulfilled through metabolic processes, and as vegetation (forbs) dries in late summer and fall the birds tend to move to areas where free water is available. High temperatures and the associated heat stress induce grouse to seek free

<sup>3</sup>R. R. Kindschy, Bureau of Land Management District Office, Vale, Oregon, personal communication.

water sources by early July in some years (Savage 1969). In winter, snow takes care of their moisture requirements, either directly or as it melts and provides free water.

## BIOTIC FACTORS

### Vegetation

A habitat manager must account for seasonal needs of sage grouse. For example, deep snow covering the spring and summer ranges may force the birds to migrate to some distant range for winter, only to return for nesting as snow depth decreases (Rogers 1964, Wallestad 1975). Where sage grouse nest and raise broods on sagebrush-covered mountain slopes or in high mountain valleys, they usually migrate to lower valleys in winter to find exposed sagebrush for food. This is common in Wyoming, Colorado, and Idaho but less true in southeastern Oregon where winters are milder and snow seldom covers sagebrush plants deep enough to make locating food a serious problem.

Vegetation structure and composition on leks (strutting grounds) differ from the vegetation complex on wintering areas or in nesting areas. Dense, tall sagebrush is seldom used for nesting cover (Patterson 1952) but is frequently used as loafing cover or as protective cover during severe winter storms (Beck 1977). In general, good habitat for sage grouse should contain openings less than 274 m (300 yd) in circumference, some dense sagebrush stands, and about equal amounts of tall and short sagebrush plants (Rogers 1964).

### Breeding Habitat

In late February and early March, cocks begin moving from wintering areas to traditional leks. A few weeks later hens congregate at these sites for courtship and mating. Leks are usually small open areas from 0.04 to 4 ha (1/10 to 10 acres) in size, but they may be as large as 40.5 ha (100 acres) or more (Call 1979).

Leks may be located at a point intermediate between the winter and summer range. In some cases, the summer and winter range may be the same area. Sage grouse prefer relatively open areas as leks (Call 1979, Keller et al. 1941,

Patterson 1952, Rogers 1964, Schlatterer 1960, Scott 1942, Wallestad 1975). Although sagebrush usually surrounds a lek, it may be low and sparse or dense (Scott 1942, Wallestad 1975). Grassy swales, natural and irrigated meadows where grass has been removed or grazed, burned areas, cultivated or natural fields adjacent to sagebrush-grass rangelands, cleared roadsides, abandoned homesteads, dry lakebeds, bare areas around small reservoirs, barren ridges, swales, bottom lands, and other open areas on all exposures may be used for strutting and mating (figs. 5, 6, and 7).

Barring complete obliteration of the physical aspects of a lek itself, generation after generation of birds will use the same lek. Occupancy of individual grounds usually extends over many years, although in the interim, new grounds are established by young birds, and others are probably passing out of existence because of changes in habitat or disintegration of a local male population. There may also be a gradual shift of sage grouse use between leks over a long period. A shift in use of leks, small ones being abandoned and large ones increasingly used, may occur toward the end of the breeding season (Dalke et al. 1960, Patterson 1952, Wiley 1973). One lek in Idaho may have been used for 90 years, although not necessarily continuously; this conclusion is based on the finding of broken arrowheads used for hunting birds. Use of such leks year after year depends on the size of the grouse population for any given year. Larger grounds may be used each year, whereas smaller ones may be temporarily abandoned when populations are low (Dalke et al. 1963).

Sage grouse apparently prefer leks adjacent to dense brushy cover. Such cover is undoubtedly important during strutting when the birds are exposed to predators, particularly raptors (fig. 8). The loss of surrounding food and cover may cause a lek to be abandoned (Carr 1968, Trueblood 1954).

Loafing and roosting sites near leks invariably support the heaviest and densest sagebrush (Patterson 1952). Optimum loafing sites are found along stream bottoms, ravines, and draws. Wallestad and Schladweiler (1974) recorded sagebrush height and canopy cover at





Figure 5.—Bare, open areas are commonly selected as sage grouse leks (Oregon Department of Fish and Wildlife photograph by A. L. Miller).



Figure 6.—Open areas of low vegetation may be used for breeding activities.



Figure 7.—Note hens on strutting grounds for breeding; they then move to outlying areas for nesting.

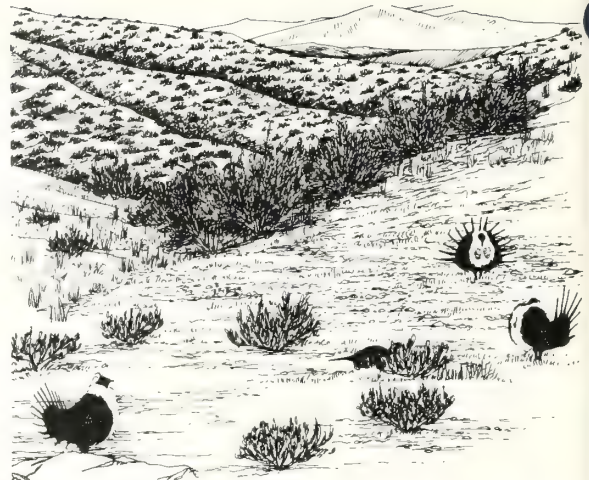


Figure 8.—Sage grouse apparently prefer leks adjacent to dense brushy cover.

110 feeding and loafing sites of cocks; 80 percent of the locations occurred in sagebrush with a canopy cover of 20-50 percent (this is also the range of canopy for which vegetation control is likely to be recommended to enhance livestock production).

Grouse may spend the day within 1.6 km (1 mi) of the leks, or they might move 3.2-4.8 km (2-3 mi) away (Batterson and Morse 1948, Scott 1942). The cruising radius of sage grouse in Idaho during the strutting season was thought to be less than 0.8 km (0.5 mi) (Pyrah 1954), whereas in Montana male grouse commonly moved up to 1.3 km (0.8 mi) from leks (Wallestad and Schladweiler 1974). Adult males in Colorado rarely ventured farther than 366 m (400 yd) from leks, but near the end of the strutting season they moved outward as much as 1.6 km (1 mi). Because sage grouse feed primarily on sagebrush during the early part of the mating season, they are more likely to abandon a lek if an adequate supply of food is not available within at least 1.6 km (1 mi). Although sage grouse may move a kilometer or more for food, they probably would not readily move that distance without adequate cover. Sagebrush should therefore be protected to a radius of at least 2.4 km (1.5 mi) from leks (Carr 1968, Gill 1965, Wallestad and Schladweiler 1974).





Figure 9.—Sage grouse nests are usually placed between or under sagebrush plants with some overhead cover (photograph courtesy of Dick Kerr).

### Nesting Habitat

Sage grouse hens build nests in the vicinity of a lek within 7 to 10 days after breeding. The nest is frequently constructed between the lek and the area that will be used for brood-rearing and summering (Autenrieth 1981, Braun et al. 1969, Wallestad 1975). Nests are made by scratching out a shallow depression, usually beneath or between sagebrush plants, that is lined with dead grass, sage twigs, and feathers (fig. 9).

Egg laying normally begins about mid-April. A few renesting hens do not complete clutches until mid-May. Incubation takes 25 to 27 days; the peak of hatching varies from the last week in May to the second week in June. The mean hatching date in Oregon is the second week of June; 20 to 30 percent of hatching occurs in May and 15 to 20 percent in July (see footnote 3). Average clutch size is six to eight eggs. A few nests have as many as 12 eggs (Patterson 1952).

A basic requirement of nesting cover is concealment of the hen and her nest (Autenrieth 1981, Girard 1935, Keller et al. 1941, Patterson 1952). Nest locations are apparently related to cover condition. Autenrieth (1981) found that when good nesting cover was available near a lek, the proximity of the nest to the lek tended to be less than when sagebrush was sparse and found only in clumps. The proximity of 306 nests to a lek was (cumulative percentages):

0-1.6 km (0.96 mi), 28.4 percent; 0-3.2 km (1.92 mi), 59.0 percent; 0-4.8 km (2.88 mi), 73.4 percent; 0-6.4 km (3.84 mi), 85.0 percent; 0-8.0 km (4.80 mi), 96.2 percent; 0-9.6 km (5.76 mi), 97.2 percent; 0-12.8 km (6.72 mi), 100 percent.

Nest sites are usually located within 3.2 km (2 mi) of a lek. Wallestad and Pyrah (1974) found that 68 percent of all radio-marked hens in Montana nested within 2.4 km (1.5 mi) of a lek; one nest was found 9.1 km (5.7 mi) from a lek. Rogers (1964) reports an unusual situation in Colorado where hens traveled from 24 to 32 km (15 to 20 mi) from the lek to nest. Hens would visit leks until bred and would then move into a vicinity close to the location of the final nest site and remain relatively sedentary until they nested. Braun et al. (1969) stated that hens in Colorado tended to make their nests in the direction of the brood-rearing and summering areas after leaving the breeding grounds.

The specific use of sagebrush as nesting cover has been documented as follows: Wyoming, 92 percent of approximately 300 nests were under sagebrush (Patterson 1952); Colorado, 92 percent of 117 nests (Gill 1965); Wyoming, 50 nests (Girard 1937); Colorado, 94 percent of the nests (Keller et al. 1941); Idaho, 35 nests (Gray 1967); and Montana, 100 percent of the nests (Wallestad and Pyrah 1974).

Some biologists believe that dense vegetation and undergrowth are preferred for nesting (Dargan and Keller 1940; Rasmussen and Griner 1938); others stated that isolated plants and open stands were favored (Batterson and Morse 1948). Patterson (1952) thought that hens preferred to nest in short sagebrush of medium density, such as is found on drier sites, in preference to the dense, tall brush found along watercourses and on moist sites. In Idaho the number of big sagebrush plants per 0.4 ha (1 acre) of nesting habitat ranged from 4,960 to 10,790 (Autenrieth 1981), and in Montana the number of sagebrush plants within 68 cm (24 in) of successful nests was 6.4 (Wallestad and Pyrah 1974). Patterson (1952) was probably referring to sagebrush from 30 to 80 cm (12 to 15 in) in height and from 6,000 to 8,000 sagebrush plants per 0.4 ha (1 acre) in locations that would permit a quick and unimpeded escape for a hen.

Most nests are hidden from above by branches that provide an umbrella effect (Autenrieth 1981, Batterson and Morse 1948, Girard 1935, Nelson 1955, Patterson 1952). Although large, full sagebrush plants are not always used for nesting cover, good growth of understory grasses aids in nesting success because it helps conceal nests from aerial predators and contributes to a microclimate that is warmer than the air temperature 1 m (39 in) above the nest. Nest temperature drops less during a hen's absence where the understory is greatest. Hens usually leave the nests to feed for brief periods twice daily—0430 to 0630 and 1800 to 1900 (Autenrieth 1981; Girard 1935, 1937; Nelson 1955; Rasmussen and Griner 1938).

Wallestad and Pyrah (1974) compared the characteristics of sagebrush around 31 successful and 10 unsuccessful nests. A significantly greater cover of sagebrush within 60 cm (24 in) of the nest within a 9-m<sup>2</sup> (100-ft<sup>2</sup>) plot was around successful nests (6.4 sagebrush plants compared with 4.5 for unsuccessful nests); and successful nests were located in stands of sagebrush with a higher average canopy cover (27 percent) than that of unsuccessful nests (20 percent). Patterson (1952) found nesting density to be lower on an overgrazed area than on an ungrazed area (one nest per 9.5 ha (23.5 acres) compared with one nest per 3.6 ha (9 acres)) and implied this was due to reduced ground cover, other than shrubs.

Height of sagebrush commonly used for nesting ranges from 17 to 79 cm (7 to 31 in). Most

nests are located under the tallest bushes available at a particular site (Autenrieth 1981; Braun et al. 1977; Gray 1967; Keller et al. 1941; Klebenow 1969; Patterson 1950, 1952; Schlatterer 1960; Trueblood 1954; Wallestad and Pyrah 1974). Stands with 20 to 40 percent canopy cover are most frequently selected for nesting (fig. 10). Many studies do not give the average sagebrush height that predominates in the area, but those that do indicate preference for the higher plants under which to place nests (table 1). The variety of sagebrush species and subspecies that occur suggests that sage grouse will nest in sagebrush of different heights in different community types.

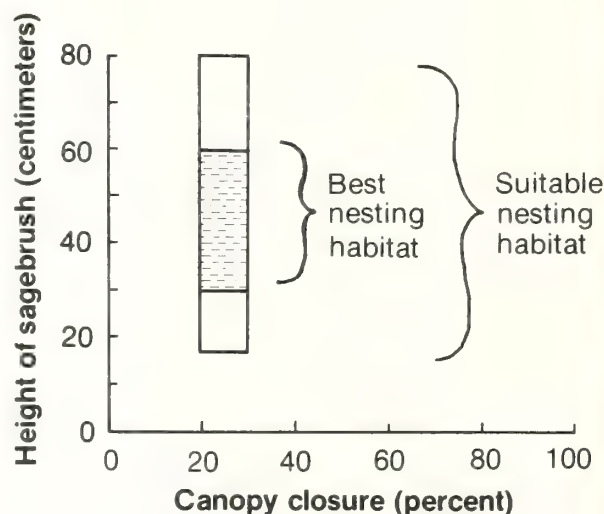


Figure 10.—The relationship of sagebrush height and percentage of canopy closure in producing suitable sage grouse nesting habitat.

Table 1—Average sagebrush height used for nesting cover

State	Average sagebrush height used for nesting		Average sagebrush height in immediate area		Authority
	Centimeters	Inches	Centimeters	Inches	
Oregon	48	19			Nelson (1955)
Wyoming	25.4-50.8	10-20			Patterson (1952)
Montana	40.4	15.9			Wallestad (1975)
Idaho	57-80	22.4-31.5	23-79	9-31	Autenrieth (1981)
Colorado	52.3	20.6	32.3	12.7	Peterson (1980)
Utah:					
Reseeded	29.2	11.5			Trueblood (1954)
Not reseeded	53.3	21.0			



## Brood-Rearing Habitat

Brood rearing is an important phase of grouse production. Fall population levels depend on the survival of young through the summer. This means that hens require well-sheltered areas that provide maximum protection for them while brooding. Protection of the brood from adverse weather and predation is extremely important immediately after hatching. Chicks may be killed by adverse weather (Carr 1968, Dalke et al. 1960, Griner 1939, Nelson 1955, Patterson 1952, Pyrah 1960).

Dargan and Keller (1940) attributed high mortality of chicks to predation rather than to adverse weather. Predation accounts for considerable mortality in chicks. Most egg predation and nest destruction in Oregon has been attributed to ravens (Batterson and Morse 1948, Girard 1935, Nelson 1955). Thus, protection from adverse weather (low temperatures, snow, rain, and high winds) and predation during the chicks' first weeks of life appears to be critical factors determining fall densities (Carr 1968).

Broods usually stay near the nest for several hours after hatching. Chicks begin feeding as soon as they leave the nest but are limited in mobility, so food in the form of suitable insects and forbs must be close by (Carr 1968, Girard 1935, Griner 1939, Nelson 1955).

The diet of chicks during their first week is chiefly insects, especially beetles and ants. Succulent forbs—such as common dandelion, common salsify, western yarrow, prickly lettuce, clover, aster, and phlox and shrub foliage—become more important as time passes (fig. 11). The succulence of favored foods appears to be an important factor influencing brood movements. Use of forbs depends on availability, so hens and chicks often remain in the vicinity of the nests for the first 2 or 3 weeks after hatching if insects and succulent forbs are available (Klebenow and Gray 1968, Patterson 1952, Peterson 1970a, Pyrah 1954, Savage 1969).

As plants mature and dry, grouse move to areas still supporting succulent vegetation. These may be lower elevation native meadows or irrigated meadows when no uplands with green vegetation are in the area (fig. 12). Grouse may also migrate upward, seeking



Figure 11.—The diet of chicks the first week is insects, especially beetles and ants. Succulent forbs become important later.



Figure 12.—Wet meadows adjacent to sagebrush stands are excellent brood-rearing areas. Succulent forbs and insects, the main items in diets of young grouse, abound in wet meadows. (Photograph courtesy of Robert R. Kindschy.)

habitats with succulent forbs, such as drainages at higher elevations, mountain meadows, and more mesic swales. The importance of upland meadows in some of the drier areas of southeastern Oregon cannot be overemphasized.<sup>4</sup> Improper livestock grazing can cause gully erosion that results in lowered water tables, drying out of meadows, and loss of valuable feeding habitat for sage grouse.

<sup>4</sup>D. A. Klebenow, University of Nevada, Reno, personal communication.



Further, piping water from springs to livestock troughs frequently dries up small, wet meadows that often occur around undeveloped springs (Thomas et al. 1979). In some States, roadsides and borrow pits are frequently used during June and July because of the moisture and succulent vegetation present, but roadsides in Nevada and southeastern Oregon are generally too dry for succulent vegetation to develop (Batterson and Morse 1948, Crawford 1960, Eng 1952, Gill 1965, Klebenow 1972, Nelson 1955, Patterson 1952, Rogers 1964).

A delay in maturing of forbs has a noticeable effect on bird movements. Savage (1968) noted that grouse did not use meadows one summer when the range was in good condition because succulent forbs were available elsewhere. Meadows are important, however, for three primary reasons: (1) Forbs are important in the diet of young birds and meadows are their primary source, especially in dry years; (2) free water is often found in meadows; and (3) young birds eat large numbers of ants that are commonly found associated with meadow ecotones and meadow remnants (Savage 1969).

Meadowlands or alfalfa fields are used as brood feeding sites; willows and sagebrush are used for resting and shading; and areas of sparse, low-growing sagebrush (within 3.2 km (2 mi) of the feeding areas) are preferred as night roosting areas (Griner 1939, Patterson 1952). In Montana, approximately 65 percent of all observations of grouse in August and September were recorded in bottom land types, such as alfalfa fields and black greasewood flats. Grouse may also be attracted to hay and alfalfa meadows by the overall lush vegetational aspect and not specifically to alfalfa as a food item (Wallestad 1970, 1975).

Although suitable food is important, all studies emphasize the need for cover to enhance brood-rearing. Brooding hens prefer relatively open sagebrush compared with dense stands. The percentage of canopy cover of big sagebrush at brood sites in southern Idaho was 8.5, significantly less than the average for the entire area, 14.3. Only 3 of 98 broods were found where total shrub cover was 40 to 49 percent; the rest were found where cover was less than 31 percent. Where there was an interspersed

of openings mixed with dense sagebrush, broods used the more open portions. The most important variable in discriminating between habitat used by broods and that not used was the number of big sagebrush plants per 37.2 m<sup>2</sup> (400 ft<sup>2</sup>). Broods occupied sites with fewer big sagebrush plants than in the overall big sagebrush vegetation type (64.3 vs. 103.7 big sagebrush per 37.2 m<sup>2</sup> (400 ft<sup>2</sup>)). Broods used areas where forbs were most abundant (Klebenow 1969, 1972). Broods in Montana were found where sagebrush canopy cover was less than 14 percent in June, July, and August and less than 21 percent in September (Wallestad 1971). Although large tracts of dense sagebrush seem to be undesirable brood habitat, small islands of big sagebrush, located within stands of low sagebrush, are frequently used as brood cover (Savage 1969, Wallestad 1971).

Grouse consumption of sagebrush intensifies as meadows and foliage of forbs dry and the incidence of frost increases, in late August at high elevations or in September and October in lower areas (Klebenow 1972, Savage 1969).

Hens with broods do not usually associate with other hens and broods early in summer, but as food plants desiccate, broods move to more mesic sites and begin to associate with other broods. Flocks of hens in late summer vary in size from several broods to several hundred sage grouse. These associations may be the initiation of fall and winter hen flocks (Wallestad 1975).

### Wintering Habitat

As snow begins to accumulate on their summer-fall ranges, sage grouse start moving to lowlands or other sites, such as windblown ridges, where their needs for forage and cover can be met throughout the winter. The extent of seasonal movements varies with the severity of winter weather, topography, and vegetative cover. Sedentary populations meet all their seasonal requirements in the same general area and, as winter approaches, simply change their use areas from meadows to sagebrush, because they live almost entirely on the leaves of sagebrush in winter (Bean 1941, Beck 1975, Patterson 1952, Wallestad 1975). Other populations

are migratory and move 24 to 32 km (15 to 20 mi) from nesting to wintering areas in Colorado (Rogers 1964), 48 to 80 km (30 to 50 mi) on the Snake River Plains in Idaho (Dalke et al. 1963), and 80 to 160 km (50 to 100 mi) in Eden Valley, Wyoming (Patterson 1952). In eastern Montana, on the other hand, movements farther than 16 km (10 mi) are uncommon (Wallestad 1975).

In seeking wintering areas, grouse initially select areas with the most palatable sagebrush; if those areas become covered with snow, they shift to available sagebrush (figs. 13 and 14). Although wintering areas may be selected primarily on the basis of the amount of snow rather than the affinity of grouse for a particular site, the forage quality of sagebrush (chemical composition) may influence which areas are used. Wintering flocks in Idaho concentrate where low sagebrush or black sagebrush occurs. They may remain on areas supporting black sagebrush until snow covers the plants and return when the plants are again available (Autenrieth 1981, Beck 1977, Call 1979, Crawford 1960, Dalke et al. 1963, Pyrah 1954). Black sagebrush in Oregon occurs primarily in southern Malheur, Harney, and Lake Counties (Dealy et al. 1981) and is probably used as winter forage where available.

Other plant communities are also used by sage grouse in southeastern Oregon (fig. 11). Low sagebrush/bunchgrass communities typically occur adjacent to or intermixed with big sagebrush communities but are distinctly separate stands associated with shallow, stony soils (fig. 15). Cleftleaf sagebrush/bunchgrass communities occur in similar situations. Threetip sagebrush occurs in Baker and northern Harney Counties and occasionally in Malheur County. Usually found adjacent to mountain big sagebrush, threetip sagebrush retains its integrity and is used by sage grouse where available (Dealy et al. 1981).

Wyoming big sagebrush is the most common sagebrush throughout the high desert in Oregon. It is more common at elevations less than 1830 m (6,000 ft) and on more xeric mountain sites than other big sagebrush communities (Winward 1980). Sage grouse use it for winter cover and forage and for loafing and nesting

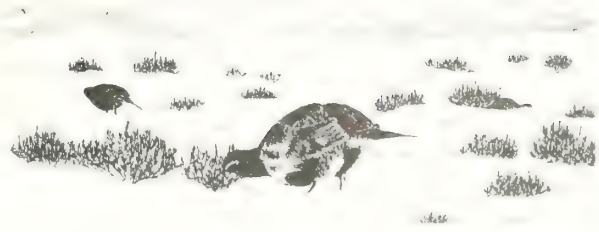


Figure 13.—In winter, sage grouse seek areas where palatable sagebrush is available as forage. The grouse will migrate to find such areas. (Oregon Department of Fish and Wildlife photograph by Vic Masson.)



Figure 14.—Stands of low sagebrush are excellent habitat for sage grouse, especially during spring, summer, and fall. Low sagebrush is also used as winter habitat where snow cover permits. (Photograph courtesy of Robert R. Kindschy.)



Figure 15.—Sage grouse winter habitat with sufficiently dense sagebrush to provide ample forage and cover.



cover where it meets the criteria for canopy cover and density.

Basin big sagebrush extends from the southern end of the Blue Mountains in northeastern Oregon and throughout the central and southeastern portions of the State. The land area occupied by basin big sagebrush constitutes a minor portion of the sagebrush complex in Oregon; much of its former range is now cultivated land. It provides good cover but poor forage.

Bolander silver sagebrush and mountain silver sagebrush/bunchgrass communities are found in seasonally moist areas in central and eastern Oregon. The two subspecies are associated with two distinct habitats, closed basins and streamside or pond-edge meadows. The basin subspecies, Bolander silver sagebrush, is distributed within the desert areas of Oregon from Prineville throughout the southeastern third of the State; the streamside-meadow subspecies, mountain silver sagebrush, is most common in east-central and southeastern Oregon where there are seasonally high water tables adjacent to streams and meadows (Winward 1980). Bolander silver sagebrush typically has a sparse understory and is poor brooding habitat, but both subspecies of silver sagebrush are palatable and are used by sage grouse for cover and winter food (Dealy et al. 1981). The different subspecies in Oregon vary considerably in palatability and plant structure. Even though they may look similar, some sagebrush ranges are much more important to sage grouse than others.

Habitat surveys conducted during the summer may give the impression of vast acreages of sagebrush available as winter range for grouse. Observations during winter, however, reveal that much of the habitat is not available because of snow depth or it is unsuitable for other reasons. For example, when snow depth in Montana exceeded 30.5 cm (12 in), sage grouse were restricted to taller sagebrush stands. Only 7 percent of the range was available when snow depth exceeded 30 cm (11.8 in) (Wallestad 1975). Sage grouse in Idaho moved to taller sagebrush types when snow depth reached about 33 cm (13 in) (Bean 1941).

Areas of greatest available canopy cover tend to be most used (Autenrieth 1981, Eng and Schladweiler 1972). Winter ranges in eastern Montana have little if any slope and are large expanses of dense (20 percent or greater canopy cover) sagebrush with an average height of 25.4 cm (10 in) (Eng and Schladweiler 1972). Grouse in Colorado used areas of less than 15 percent slope and preferred southwest exposures in winter (Beck 1975, Beck and Braun 1978). This association with dense stands of sagebrush usually begins in September and continues through the breeding and nesting seasons. In fact, 15 percent canopy cover of sagebrush appears to be the minimum acceptable for sage grouse winter and nesting habitat (Wallestad 1971, 1975; Wallestad and Schladweiler 1974).

Flocks may segregate by sex in the winter when females use denser stands of sagebrush than do males. Sagebrush density (determined for brush exposed above the snow) averaged from 46.0 to 63.7 plants/0.004 ha (0.001 acre) for males in two winters and 68.2 to 77.5 plants/0.004 ha for females (Beck 1977). The maximum may be about 49.6 plants/0.004 ha with an average height of 55.8 cm (22 in) and a canopy cover of 38.1 percent (Autenrieth 1981).

Winter is usually the critical period of the year for most wildlife and the most taxing on their physiological systems, but if the grouse have adequate and suitable sagebrush, they usually emerge from winter in good physical condition. Yearling and adult males and females even gained weight in late winter (January-March) in North Park, Colorado (Beck and Braun 1978).

## Animal

### PREDATION

Losses of sage grouse nests and young to predation are often high and are probably the most significant factor in determining annual recruitment to the population (Allred 1942, Autenrieth 1981, Batterson and Morse 1948, Gill 1964, Patterson 1950). For example, one study in Oregon in which 66 of 131 nests were destroyed by predators showed that the greatest single limiting factor of sage grouse was



nest predation by ravens (Batterson and Morse 1948). Ravens were also the only significant avian predator on sage grouse nests on Autenrieth's (1981) south-central Idaho study area. In other areas, magpies may be important nest predators (Brooks 1930). According to Gill (1965), hens are only present on the nest while actually laying eggs during the 10- to 14-day laying period. They are commonly absent from nests from one-half hour after sunrise to 1 hour before sunset, and nests are highly vulnerable to predators.

Crows also prey on young grouse (Grondahl 1956). But predation by crows is reduced when the grasses and forbs begin to grow and conceal the nests better. In addition, other food items, such as insects, become more plentiful as vegetation develops, and crows shift their feeding to those sources, which reduces their efforts to locate unattended nests. Avian predators have more difficulty finding nests that are concealed by vegetation. Terrestrial predators may find nests more by smell or by accident than by sight, and good cover probably makes their efforts to find nests less successful. Where badgers were abundant in Oregon, Nelson (1955) found that they were an important predator of sage grouse nests, and Gill (1965) found that badgers and Richardson ground squirrels in Colorado were efficient predators of sage grouse eggs. The Richardson ground squirrel may also be an important predator on young sage grouse (Keller et al. 1941).

## Management Relationships

The effects of sagebrush removal and/or modification on a population of sage grouse can be evaluated by the following: (1) presence or absence of grouse on treated areas and the relative use of the areas by birds as indicated by dropping counts, (2) changes in population levels as indicated by numbers of strutting males on all leks, and (3) direct observation of birds on and around the treated areas (Wallestad 1975).

## EFFECTS ON BREEDING ACTIVITIES

Sagebrush control may increase or decrease the desirability of leks, depending on circumstances. Although openings in sagebrush habitat may be created by killing the shrubs, increased grass density may prevent the openings from being used (Carr 1968). One of the best documented instances of the detrimental effects of sagebrush removal on sage grouse involved an isolated population in Meagher County, Montana. Five leks were eliminated as a result of sagebrush being sprayed and 49 percent (4781 ha or 11,808 acres) of available sagebrush types being converted to cropland (Peterson 1970b). One lek averaged 54 males during 13 breeding seasons. Within 2 years after it was sprayed only three males used it, and it was then totally abandoned (Peterson 1970b).

A 4858-ha (12,000-acre) sagebrush spray project in Wyoming was responsible for the elimination of sage grouse from a winter range that supported 1,000 birds prior to treatment. Four leks on the treated area declined from a total population of 50 males to none 4 years after treatment with 2,4-D (2,4-dichlorophenoxyacetic acid). Eight years after treatment, the leks had a total of 31 males. Adjacent grounds in unsprayed areas had only minor fluctuations in numbers of birds during this same period (Higby 1969). Complete block spraying of an area surrounding a large lek in Colorado resulted in almost complete abandonment of the lek within 7 years of spraying (Braun and Beck 1976).

Wallestad (1975 p. 37-39) observed that:

Treatment of 751 acres (24 percent of the total suitable habitat adjacent to the King Ranch Strutting Ground) resulted in a 50 percent reduction in cocks the following year. However, 3 years post-treatment the population had recovered to pre-treatment levels. Spraying of 640 acres (11 percent reduction in suitable habitat) resulted in no significant post-treatment population change on the adjacent South Pike Creek Strutting Ground. A new ground (possibly because of spraying) was established 1.5 miles to the northeast, the

year following treatment. Two hundred fifty-three acres adjacent to the Highway Strutting Ground was scheduled for a partial kill of sagebrush (65 percent reduction in crown coverage); however, the small size of the area, combined with a light actual kill (25 percent reduction in coverage) produced no major effect on the strutting ground cock population.

Of the 1,090 acres of sagebrush sprayed adjacent to the North Yellow Water Strutting Ground, 839 acres (31 percent of the total suitable habitat) had a canopy coverage exceeding 15 percent prior to treatment. The sprayed area was also the largest block of continuous habitat in the area. In the two post-treatment years there was a 63 percent loss in cocks on the strutting ground while other grounds remained relatively stable.

Total numbers of male sage grouse on 3 leks within 0.5 miles of the treated area increased an average of 28 percent from pre- to post-treatment years. In the face of an increasing population, it appeared that sagebrush treatment had no effect on the sage grouse population. When compared to control leks in the same population, however, the effect became more pronounced. Total numbers of males on two grounds further than 2 miles from treated areas increased an average of 323 percent during the same period. Number of sage grouse observed on grounds within 0.5 miles of treated areas and those further than 2 miles led to the conclusion that differences were related to sagebrush spraying.

The effects of sagebrush removal on use of leks probably varies in different areas, depending on many factors, but evidence indicates that the results can be disastrous to some populations. Impacts seem to relate mostly to the amount of food and cover remaining within approximately 1.6 km (1 mi) of the leks.

## EFFECTS ON NESTING HABITAT

Cover and food are important habitat requirements in nesting areas. Nesting commences in early spring before many plants have started growing, so sagebrush serves as the primary source of food during this period. From this standpoint, sagebrush control could eliminate nesting in an area by eliminating the hens' food supply. Grouse ceased nesting on newly sprayed areas with less than 5 percent live sagebrush canopy cover, and nesting was nearly nonexistent in older sprayed areas with about 5 percent live sagebrush cover. Broods were less affected by herbicide treatment, however, and they continued to use some sprayed areas (Carr 1968, Klebenow 1970).

Where sage grouse have been observed in areas with a strip-spray pattern, the majority were within 23 to 29 m (75 to 95 ft) of unsprayed strips. They apparently preferred unsprayed sagebrush sites, or sites with similar canopy cover, to treated areas (Martin 1965).

Sagebrush control with 2,4-D usually reduces the quality of nesting cover and nesting density, but dead sagebrush stalks and increased grass understory normally provide cover for a few years that partially offsets the loss of living sagebrush. The greatest limitation imposed on nesting distribution by control of sagebrush would be the elimination of food required by the incubating hens. Unlike plowing and reseeded, which tend to increase the amount and variety of forbs, 2,4-D tends to reduce forbs and sagebrush. Thus, alternative foods that could supplement sagebrush in the diet, at least toward the end of incubation, might also be reduced (Carr 1968).

Although nests may be found under dead sagebrush, protection and concealment are less than under live sagebrush. Consequently, desertion and destruction of nests in such circumstances are greater.

Trueblood (1954) compared seeded, reseeded, and nonreseeded areas and found that nesting density, nesting success, and hatching success were lower on plowed and reseeded areas. Reseeded lands produced one nest for every 9.5 ha (23.5 acres) and nonreseeded lands one nest per



7.8 ha (19.2 acres). The average height of nesting cover on reseeded lands was 29.2 cm (11.5 in) and 53.3 cm (21 in) on areas not reseeded. No nests were found more than 228.7 m (250 yd) from water. Hens nesting in reseeded areas preferred scattered remnants of sagebrush cover, but more than one-fourth of the nests were found beneath clumps of grass. Although nesting suitability was closely related to precipitation on reseeded ranges, it was relatively independent of precipitation on ranges not reseeded. Nesting hens were more easily detected by observers on reseeded areas than on areas not reseeded.

### EFFECTS ON BROOD-REARING AND SUMMER HABITAT

The effects of sagebrush control on brood-rearing and summer areas seem to depend mainly on: (1) forb and grass production subsequent to treatment and (2) the amount of sagebrush retained for cover.

A reduction in cover of sagebrush caused by spraying can reduce the brood-carrying capacity of an area. Old sprayed areas where sagebrush and forbs have regrown since the original treatment may be used by broods, but not the more recently sprayed areas with high sagebrush kills (Klebenow 1970, Martin 1970, Rogers 1964).

Autenrieth (1969) conducted a 3-year study in Idaho after a 1965 spray project and concluded that spraying strips in a relatively high precipitation area (33 cm (13 in) annual precipitation) may benefit brood-rearing habitat because of a quick recovery of important forbs, such as dandelion and western yarrow. After 3 years, the average cover of dandelions in the spray strips was 17.2 percent compared with 11.2 percent in the leave strips. The leave strips were used by broods for feeding and occasional roosting. Because of the relatively high elevation (1784 m or 5,851 ft) and annual precipitation, a mountain meadow effect was created by strip spraying. Most sage grouse habitat occurs at low elevations with one-half (or less) the annual precipitation of the Idaho study area; in such areas eradication of sagebrush is usually detrimental to grouse populations (Braun et al. 1977).

Total forb cover is not as important to sage grouse as cover of highly preferred species of forbs. Sagebrush control with 2,4-D reduces most forbs and makes sprayed areas less suitable for summer feeding (Autenrieth 1970, Braun and Beck 1976, Carr 1968, Klebenow and Gray 1968, Martin 1970, Peterson 1970a). Many insects eaten by young sage grouse are killed by the 2,4-D ester used with an oil carrier (Hanson 1952).

In many areas, streams flow through sagebrush-covered valleys and along draws in rolling hills. Meadowlike openings that can be created adjacent to streams by spraying or plowing the sagebrush could be beneficial to sage grouse broods, provided livestock are not permitted heavy early grazing in these areas. Livestock tend to concentrate on meadows, however, and to graze them so heavily that sheet erosion or gully erosion begins. Such intensive use of small meadows will render them of little value to grouse (Oakleaf 1971).

### EFFECTS ON WINTER HABITAT

The effect of sagebrush control on sage grouse in winter depends mainly on the extent of sagebrush kill. Because sagebrush is practically the only food eaten by grouse in winter (Carr 1968, Patterson 1952, Wallestad 1975), the grouse will be forced to abandon areas where adequate food and associated cover are no longer present (fig. 16).



Figure 16.—This valley was converted from sagebrush to crested wheatgrass. Although increased grass production in some areas will reduce livestock grazing in adjacent sagebrush stands, the treated areas will be of little value to grouse. Evaluation of overall impacts on sage grouse should be made before sagebrush ranges are converted to grasslands.



Wintering areas hold some of the highest densities of sage grouse, and they may be used on an annual basis by birds from several leks. Such areas may be the primary habitat for 7 to 8 months of the year and may have considerable influence on grouse distribution over a wide area (Eng and Schladweiler 1972). Wallestad (1975) further stressed the importance of such areas by linking them with spring habitat and calling them wintering-nesting complexes. Thus, a sage grouse population may be more sensitive to the loss of wintering areas, which sometimes incorporate the breeding-nesting complex, than to the loss of habitat used during summer and fall (Eng et al. 1979).

Winter use of sagebrush control areas by grouse is proportional to the severity of treatment. Treatments that kill the smallest percentage of sagebrush affect grouse use the least, and the duration of the adverse effect is shortest. For example, Pyrah (1972) determined that herbicide applied in strips that killed only a part of the sagebrush sprayed, block partial kill, mechanical treatments, and total kill spray (in that order) were increasingly detrimental to grouse. Virtually no winter use occurred in areas of total sagebrush kill. Higby (1969) studied an area in Wyoming where more than 80 percent of the sagebrush cover was destroyed over a 5-year period in a 4858-ha (12,000-acre) treatment project. Prior to treatment the area supported approximately 1,000 birds in winter, but there was practically no winter use on the area during the 5-year post-treatment study.

#### EFFECTS OF FIRE ON GROUSE HABITAT

Wildfires are natural with effects that vary depending on areas burned and intensity of the fire. At times, hot wildfires destroy important wintering areas for sage grouse.

A fire in the right place, at the right time, and of the correct size and intensity can create an opening that birds may use as a lek. Such openings, 0.4 to 4 ha (1 to 10 acres) in size at the elevations used for breeding, may be beneficial to grouse in homogeneous sagebrush habitats (Dalke et al. 1963, Klebenow 1972, Schlatterer 1960).

Sage grouse prefer light to moderate sagebrush density for nesting. Where sagebrush is dense (in excess of 20 to 40 percent canopy cover) and greater than 61 cm (2 ft) in height, controlled burning to achieve a mosaic of sagebrush and grassland with a variety of sagebrush heights would probably be beneficial to the birds (fig. 17). Repeated burning could be adverse in this case, as would large, hot fires that removed an excessive amount of cover (fig. 18). Where cover is already limited, fires could cause adverse conditions for the grouse (Griner 1939, Pyrah 1963).

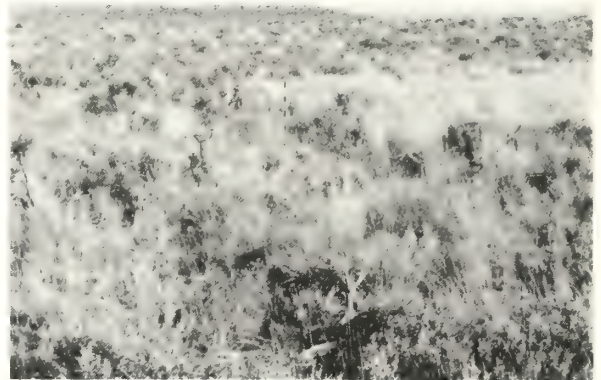


Figure 17.—Fires that create mosaic patterns in dense sagebrush stands and that leave sagebrush plants scattered throughout the burn create openings that are beneficial to sage grouse.



Figure 18.—A hot fire almost completely eliminated sagebrush from this large area and destroyed the area as sage grouse habitat.

Diversity of habitat types, both in terms of food and cover, should be the objective. Planned fire can produce favorable openings and higher yields of forbs for grouse in summer habitat (Blaisdell 1953). But fire is not desirable in winter habitats because retention of sagebrush is essential on winter ranges. Even tall, decadent sagebrush, not useful for nesting or brooding, may be important during severe winters when most other sagebrush could be covered by snow (Call 1979).

Fires are both beneficial and detrimental to sage grouse habitat, depending on the particular area and situation. Vegetation is a dynamic resource, and sage grouse needs are best met with a mixture of successional stages and plant species composition that *always* includes sagebrush. Such conditions have been accidentally achieved by wildfires and can be achieved intentionally with wise planning.

## Animal Management

### EFFECTS OF LIVESTOCK GRAZING

There are three primary effects of livestock grazing on sage grouse habitat: (1) changes in composition, density, and structure of vegetation; (2) disturbance of nesting hens and possible trampling of nests; and (3) removal of brood forage and cover in meadows.

Many sagebrush ranges on public lands are grazed by cattle in late spring, summer, fall, and winter and by domestic sheep in winter. Spring and early summer grazing by livestock removes a high percentage of grass and forbs at the time when sage grouse are turning to forbs as their primary forage. The presence of succulent forbs in brood-rearing areas is highly important to young sage grouse. Although the dependence of newly hatched chicks on insects is high, by the time they are 4 to 8 weeks old their diet consists of about 75 percent forbs and 15 percent sagebrush leaves (Savage 1969). Therefore, rapid removal of forbs by livestock on spring and summer ranges may have a substantial adverse impact on young grouse, especially where forbs are already scarce. By May, adult grouse also shift from diets dominated by sagebrush to diets dominated by forbs.

Grazing domestic sheep on sagebrush ranges is a common practice in winter. In some areas sagebrush has been grazed so heavily in consecutive winters that the brush has been severely damaged. If such use occurs on important sage grouse wintering areas, the grouse may have difficulty obtaining sufficient forage for their needs, especially during severe winters with deep snow (Call 1979). The degree of impact therefore varies with the time and intensity of grazing and the severity of the winters.

Forced movement of cattle and sheep across rangelands is commonly practiced, particularly in spring and fall. There may be significant impacts on nesting hens and young broods caught in the paths of such drives in the spring. Nests are known to have been deserted because of disturbance by sheep and cattle (Autenrieth 1981, Rasmussen and Griner 1938). In fact, grazing by sheep is much more detrimental to a sage grouse nesting area than is grazing by cattle (Girard 1937).

On two occasions bands of sheep were noted to have caused hens to flush and simultaneously to flip eggs out of their nests. Sheep subsequently stepped on these eggs, destroying them, and the nests were deserted in both cases (Patterson 1952). Sheep have also destroyed nests by stepping into them. In a few cases, nests were placed on open ground between shrubs and could have been destroyed by livestock activities, but no such destruction was recorded. There is no indication that livestock are a serious factor in destruction of nests, although desertion of nests because of livestock activities is frequent under certain conditions.

Desertion of nests by sage grouse is most prevalent in the vicinity of sheep bed-grounds. Bands of 2,000 to 3,000 sheep seriously disturb nesting activities. Patterson (1952) noted that a period of nest desertion coincided with several thousand sheep that began moving into his study area en route to their summer ranges. Most deserted nests were either preincubated or in the early stages of incubation. Nests were seldom deserted, however, after incubation was well underway. During incubation, several birds were flushed from nests by sheep, but the nests were not deserted.



Hens abandon their nests with little provocation during the egg-laying period (mid-April through early May). Yearling hens are prone to abandon their nests even when disturbed during incubation. The impact of a livestock drive could, therefore, be great because yearling hens are usually the largest reproductive age class. It is therefore best to avoid known nesting areas (within 3.2 km (2 mi) radius of leks) from mid-April to early June to reduce abandonment of nests by sage grouse (Autenrieth 1981).

Upland meadows have seriously deteriorated because of excessive livestock grazing on public lands in Nevada (Oakleaf 1971), Oregon, and other Western States. Sage grouse use in these areas has decreased because of the diminished food supply (fig. 19). Meadows provide a source of food, especially forbs, and water that is usually absent or not available on adjacent, more xeric rangelands (Savage 1969). Spring-fall and "season long" grazing have caused a marked deterioration in meadows with related gully cutting and lowering of the water table. This situation may be one of the most severe negative impacts on sage grouse in the Great Basin. Although excessive livestock grazing will cause upland meadows to gradually deteriorate, light grazing may produce benefits to grouse. Sage grouse are attracted to the green regrowth of aster, yarrow, and common dandelion on grazed meadows. The regrowth is more succulent and contains more crude protein and less fiber than ungrazed forage (see footnote 4, p. 9).

Mesic sites, such as stream bottoms, are usually heavily grazed by cattle before they seek forage on less accessible, rougher terrain (fig. 20). This is also true on upland meadows. It is difficult, expensive, and usually controversial to establish a livestock management system that will protect upland or streamside meadows. Autenrieth (1981) suggested, however, that one technique for protecting meadow forbs from livestock trampling and grazing is to fence the streamside meadow and leave access gaps for water. Even with this costly system, grazing may be allowed only once every 3 years on meadows if precipitation does not exceed 18 to 23 cm (7.1 to 9.1 in) per year. If precipitation approaches 30 cm (11.8 in) per year, he suggested grazing might be permitted in August when young birds have become mobile.



Figure 19.—Upland meadows in sagebrush stands are important to sage grouse broods. Intensive livestock grazing has caused serious deterioration of these meadows.

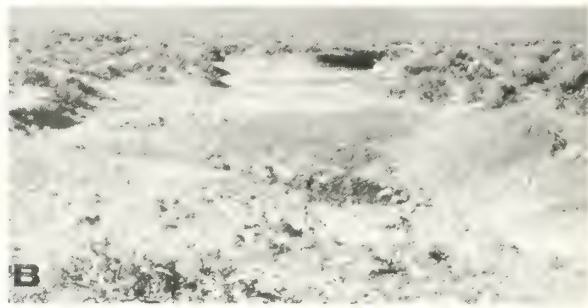


Figure 20.—Mesic habitats along stream bottoms usually receive intensive grazing by livestock (A). Such heavy grazing in spring and early summer removes most of the forbs preferred by sage grouse (B).

## EFFECTS OF HUMAN DISTURBANCE

Human activities in sage grouse habitat cause degrees of disturbance. Such activities vary from occasional harassment to disruption of the nesting cycle to elimination of use on critical winter ranges.



Daily human disturbances on sage grouse leks could cause reduction in mating, and some reduction in total production. If flushed, grouse usually fly from the strutting ground and do not return again that day. Some leks are known to the public and are visited by photographers and other interested persons to watch the annual courtship rituals. Such activities need to be curtailed if they disrupt mating. Grouse are tolerant of automobiles and may be watched from fairly close range if the observers do not leave their vehicles. But the instant a person leaves a vehicle the grouse become alarmed and generally take flight, not to return again until the next day. Fortunately, the mating season is fairly long (up to 2 months) so receptive hens will usually be mated.

Off-road vehicles occasionally run over a nest, but the amount of loss is probably insignificant. Organized motorcycle or four-wheel drive races across sage grouse nesting habitat, however, can cause substantial loss of production from direct destruction of nests, from abandonment of nests during egg-laying, from destruction of young chicks, or from all three. If sage grouse production is a management goal, then it is wise to postpone such races until after the first of September when the birds are old enough to fly out of harm's way.

There is also much exploration for oil and gas in some States. The effects of these activities on sage grouse and their habitat is poorly known and needs further evaluation.

## Management Tips

Where sage grouse are to be managed as a featured species, their primary habitat requirements need to be identified and their habitat maintained or enhanced to meet those needs. The following management tips (adapted from Autenrieth et al. 1982, Braun et al. 1977) are designed to help a manager achieve this goal.

### VEGETATION MANAGEMENT

Habitat management, which is largely sagebrush and forb management in the case of sage grouse, is critical to the perpetuation of grouse populations. Sagebrush-grassland ranges will continue to be altered, whether by design, by

accident, or by natural succession. Planned modifications could include chemical control, chaining, plowing, beating, disking, and burning, with or without reseeding. Some project considerations for controlling sagebrush that will protect important grouse values are:

1. The Federal land management agency and the State wildlife agency should coordinate closely in planning sagebrush treatment projects. A minimum of four seasons is needed to gather data on grouse use of the area prior to preparing final project plans. Areas determined to be important for nesting, brood-rearing, or wintering should not be disturbed until, and unless, the treated sagebrush areas become suitable habitat for meeting these needs.

2. Project plans for sagebrush control should include provisions for long-term quantitative and qualitative measurements of vegetation before and after treatment. This will provide information on effects on grouse habitat and populations that will be valuable in planning further projects. The land managing agency could take the responsibility for evaluating the project as it relates to changes in habitat, and the wildlife agency could assume responsibility for measuring effects of the project on sage grouse and other wildlife.

3. No control work should be considered where live sagebrush cover is less than 20 percent, or on steep (20 percent or more gradient) upper slopes with skeletal soils where big sagebrush is 30 cm (12 in) or less in height.

4. Whenever sagebrush control is determined to be desirable in sage grouse habitat, for whatever reasons, less damage to sage grouse populations will occur with either (1) partial kill, whether by spraying, chaining, plowing, or other means; or (2) creation of strip patterns or mosaics (fig. 21). Partial kill leaves sagebrush and forbs essential for grouse survival and still permits substantial increase in grass production for livestock. It also helps to retain snow and moisture longer in the spring, which creates better growing conditions for forbs and grasses later in the season.



Figure 21.—Sagebrush treatment projects can be designed to produce benefits for livestock while maintaining adequate habitat for sage grouse. This project involved the strip spraying method. (Photograph courtesy of Robert R. Kindschy.)

In strip patterns, the widths of treated and untreated areas can vary for the convenience of the application technique, but treated areas should be a maximum of 30 m (100 ft) in width, and untreated areas need to be at least as wide as treated areas. Alternate strip sagebrush removal or spraying generally has little effect on sage grouse, especially where only partial kill (less than 60 percent) is involved. In creating mosaic patterns, the treated areas should be no more than 274 m (300 yd) in circumference with similar size areas of untreated brush interspersed between the treated areas. The untreated areas can be manipulated when food and cover plants in the treated areas attain composition (or value to grouse) comparable to that of the untreated areas.

5. Treatment of sagebrush is detrimental to sage grouse if undertaken within the breeding complex. No sagebrush control should be done within approximately 3 km (2 mi) of a lek. All areas to be protected from treatment need to be clearly defined on the project maps, and close supervision is critical.

6. Streamsides, meadows, and secondary drainages (dry or intermittent) need to retain their integrity. A minimum of 100 m (330 ft) of living sagebrush should be retained adjacent to the edges of meadows and drainages to provide essential cover for broods and adult birds that use these areas for foraging. Onsite inspections will enable biologists to assess the desirability of increasing the width of untreated strips in

specific areas. Erosion along drainages has frequently been increased by excessive livestock grazing and trampling. Consequently, water tables have been lowered, which causes an increase in xeric species. Methods should be devised to raise water tables, decrease erosion, and increase mesic species that will benefit grouse and stabilize the watershed.

7. Sagebrush should not be treated in areas known to have supported wintering populations of sage grouse over the years. Periodic winter observations will enable biologists to determine the critical areas to be protected for survival of grouse.

8. Spraying should be done with either a helicopter or ground equipment to obtain precise application. Spray should be applied when wind velocity is less than 10 km (6 to 7 mi) per hour.

Chemicals other than 2,4-D should be considered for control of sagebrush. The loss of forbs on sage grouse range is one of the serious problems in spraying with 2,4-D. The phenological development of forbs is critical and must be evaluated carefully before treatment. Carpenter (1974) tested applications of 2,4-D on varying amounts of snow cover. As snow cover diminished, forb loss increased. For example, an application in Middle Park, Colorado, on April 4 killed 26 percent of the sagebrush with no forb mortality. An April 17 application killed 63 percent of the brush and 17 percent of the forbs.

Round-Up applied to sagebrush in winter will kill only vegetation protruding above the snow (Autenrieth 1981).<sup>5</sup> It kills all plants on contact, but forbs are dormant and are frequently covered by snow during this period. So the herbicide should have no effect on them.

Chaining sagebrush (pulling a 90-120-m (98-131-yd) ship's anchor chain between two crawler tractors) is one mechanical method of

<sup>5</sup>The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.



destroying sagebrush by breaking off the woody portions or tearing up the entire plant. In this method the tractor operators can exercise precise control over areas treated and can produce any type of treatment patterns desired. The amount of brush removed can also be controlled; that is, some areas are chained twice to increase the amount of sagebrush killed.

Plowing of sagebrush with a crawler tractor will kill a high percentage of the brush. This method may be used where sagebrush is too low for chaining to be effective and the understory is not adequate to carry a controlled burn. Seeding of forbs and grasses will be necessary after plowing.

## LIVESTOCK MANAGEMENT

1. Livestock grazing, primarily by cattle and sheep, is the dominant use of public rangelands. Where sage grouse are to be a featured species, it is paramount that only light grazing be permitted on important sage grouse wintering areas. Heavy grazing (in excess of 50 percent of current year's growth) may leave inadequate forage for grouse and will gradually cause a decline of sagebrush in the plant species composition. Light grazing (less than 30 percent of current year's growth) may benefit grouse in deep snow conditions by uncovering sagebrush plants, making them more available for use by grouse. Grazing by all ungulates will need to be monitored to ensure that sagebrush on the important wintering areas is not permitted to deteriorate.

2. Grazing domestic sheep on sage grouse nesting areas is best delayed until about the 1st week in June, or until the young grouse have hatched. Domestic sheep may cause considerable abandonment of nests by sage grouse around sheep bed-grounds, trailing areas, and feeding areas (Autenrieth 1981, Patterson 1952, Rasmussen and Griner 1938). Shepherders can be instructed to bypass or otherwise avoid identified prime nesting areas when trailing sheep from winter to summer ranges.

3. Cattle do not commonly cause abandonment of nests or trampling of nests and may be grazed during any season as long as sagebrush and forb components do not deteriorate as a result of such activity.

4. Grazing management may be used to help create the plant structure and composition desired for sage grouse—manage the sagebrush for an average height of 30 to 80 cm (12 to 31 in) and an average composition of 20 to 30 percent. Good grouse habitat should have from 5,000 to 10,000 sagebrush plants per 0.4 ha (1 acre).

5. Livestock grazing of sagebrush ranges during years of unusually low precipitation and poor plant growth will cause an earlier than normal removal of grasses and forbs. This can have a serious impact on grouse dependent on forbs in that locality. In important sage grouse nesting and summering areas, livestock grazing should be monitored to protect at least 50 percent of the annual herbaceous vegetation (by weight) prior to mid-September. After mid-September, grouse commence feeding on sagebrush and increased livestock grazing on herbaceous vegetation will not be detrimental.

## WATER DEVELOPMENT

Grouse concentrate around water sources in late summer and fall when forbs have desiccated. This suggests that grouse habitat can be improved by providing water near meadows or other good forb-producing areas, or by managing water for livestock so that water is available to grouse throughout the summer and fall. It is probably preferable to provide such water at ground level, such as from a water tank overflow, or by constructing small rocky pools with concrete bottoms, but any water that can be reached will be used (fig. 22).

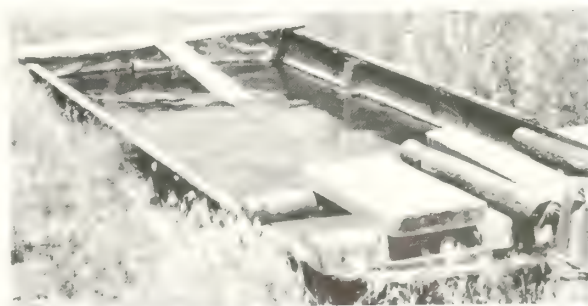


Figure 22.—Livestock water troughs are commonly used by sage grouse. Ramps for birds should be installed in all water troughs. Surplus water should be permitted to overflow onto the ground for use by all forms of wildlife.



It is best to fence springs in brood-rearing areas and to pipe water for livestock to an outside stock tank with a float valve system. When the tank is full, water can be allowed to run out of the spring and across the fenced meadow to stimulate production of forbs and grasses (Thomas et al. 1979).

It is good to fence reservoirs and to pipe water to an outside trough. Storing water in the reservoir will ensure availability of water for grouse and other wildlife in late summer.

Guzzlers can be installed on sage grouse summer range where free water is limited in quantity or is erratically available. Grouse will use water on a daily basis by late summer. A wide variety of guzzlers and water developments can be constructed to suit the needs in a given circumstance. Guzzler designs have been reviewed by Wilson (1977) and Roberts (1977).

## FENCING

Barbed wire fences kill many large birds, especially when the fences are located in swales and on ridge lines where flying birds come on them unexpectedly. Owls, falcons, sage grouse, and other birds have flown into barbed wires and have been killed. At one site near Randolph, Utah, for example, a conservation officer of the Utah Division of Wildlife Resources counted approximately 36 carcasses of sage grouse along 3.2 km (2 mi) of fence in 3 winter months of the first winter the fence was in place (fig. 23). Steel posts were placed about 10 m (33 ft) apart with stays between, which made the fence somewhat inconspicuous (Call 1979). Trueblood (1954) also reported that young grouse were often killed when they flew into fences built to control cattle.

Sage grouse are bulky birds and not very maneuverable. They frequently fly low and fast across sagebrush flats, and new fences in sage grouse habitat can be deadly to birds that strike them. When a new fence is constructed in sage grouse habitat, the danger to sage grouse can be reduced by hanging colored tape or cloth strips from the top wire to make the fence more visible to flying birds.



Figure 23.—A new fence to control cattle killed at least 36 sage grouse in a 3-month period; note the sage grouse feathers. Flagging should be hung on newly constructed fences in sage grouse habitat to warn birds of the fences.

Fencing meadows can protect them against excessive livestock grazing and can provide important advantages to the grouse. Meadows used by grouse for brood-rearing can be important to the survival of young grouse, especially the first 2 months after hatching.

## VISITOR AND VEHICLE MANAGEMENT

Some sage grouse leks are well known to the people of local communities who enjoy visiting them to photograph or to watch the strutting activities of the grouse. Public awareness campaigns, including notices published in local newspapers each spring, should inform interested people to remain in their automobiles and not create disturbances that cause grouse to leave the leks. Notices (signs) making the same points can also be posted along roads leading to the lek.

Of primary concern on public lands is the authorization of use of off-road vehicles (ORV) in habitats critical to sage grouse. Public land managers must continue to evaluate all potential impacts on the environment before and during such events. It may be necessary to stipulate that all such events must be conducted after the sage grouse's reproductive period, or that activities must be conducted in areas where no loss of habitat will occur.

Organizers of ORV events on public lands must be aware of the potential for fire caused by hot mufflers and tailpipes or by sparks or hot exhausts in brushy or grassy areas. Close supervision of organized events is essential to keep unexpected fires from destroying important sage grouse habitats (Call 1979).

## FIRE MANAGEMENT

Fire is a natural element to which most animals have become adapted. When properly applied, fire can be successfully used in perpetuating the kinds of habitats and desired structural conditions that are essential to sage grouse (Call 1979).

Wildfires that "hot burn" winter and nesting habitat can be devastating to a sage grouse population that depended on the areas burned (Autenrieth 1981). Sagebrush should be reestablished on such areas as soon as possible by the most appropriate reseeding or resprouting methods. Reseeding, the least expensive method, should be used if suitably adapted sagebrush seed can be obtained. Stem-cutting propagation is a method that can produce new sagebrush plants in a relatively short time but may be too expensive for establishing sagebrush plants over large areas. Wallace and Romney (1972) demonstrated that big sagebrush cuttings were easy to root when succulent, vigorous material from young plants was treated with 0.3 percent indolebutyric acid and maintained in a mist chamber. Cordero and McKell (1979) tested 8- to 12-cm (3.1- to 4.7- in) cuttings of terminal and lateral twigs in experiments with Wyoming big sagebrush and mountain big sagebrush. Results indicated that cuttings obtained in winter during dormancy showed more rooting activity than those collected from growing plants.

A list to consider when fire is used as a management tool follows:

1. Fire is an inexpensive tool that may be used for habitat manipulation, but all projects must be carefully evaluated, planned, and supervised. A set of clear objectives is essential.

2. Fire is best used in a manner that results in a mosaic pattern of shrubs and open areas, where the resultant openings range in size from 0.4 to 4.0 ha (1 to 10 acres).

3. Large, hot fires may remove an excessive amount of cover or may sterilize the soil.

4. Burning within an area should be done on a rotational basis, different patches burned every few years, with as long as 20 years between burning treatments on each site. This will produce a diversity of habitats within the general area. Timing of treatments over the years will depend on sagebrush response and growth rates at the specific sites.

5. Best results from burning occur in late April and early May when dry grasses and other herbaceous fuels from the previous growing season will carry a relatively cool fire. This will leave some sagebrush and still create openings for additional growth of grasses. Fires in late spring and early summer, however, could destroy many nesting birds and other young wildlife, including sage grouse; so use of fire is preferable when young are capable of escaping. At times, it may be necessary to use prescribed fire in the spring to obtain the desired changes in habitat. Strip burns that do not exceed 45 m (50 yd) in width and 90 m (100 yd) in length create desirable openings for sage grouse (Autenrieth 1981).

6. Sagebrush habitats identified as important wintering areas that are still in vigorous condition should remain intact. Grouse depend on leaves of sagebrush in such areas, not on potential development of grass and forbs in the understory or interspersed openings. If important stands of sagebrush used by grouse for wintering have deteriorated because of such things as insects, old age, or livestock grazing, the manager should initiate measures to rejuvenate the stand by light chaining, by reduced grazing, or by other means.

7. The burning techniques used by Beardall and Sylvester (1974) have been effective on sagebrush lands where precipitation is 30 cm (11.8 in) or more. The four primary elements needed for a successful burn are: (1) wet soil; (2) windspeed in excess of 12.8 km (8 mi) per hour and gusty; (3) fine fuels of 278-320 kg (611.6-704 lb) per 0.4 ha (1 acre); and (4) no burning after spring grass growth reaches 5 cm (2 in) unless burning is to improve the forbs in the community. Prescribed burns should be conducted when plants preferred as food by sage grouse are dormant (Wright 1974).



8. Livestock concentrate on burned areas and eat the new growth, so they need to be carefully managed. Haphazard burning and heavy grazing accelerate sagebrush reinvasion, soil erosion, and loss of forage plants desirable for both livestock and grouse (Pechanec et al. 1954). Grazing use must therefore be regulated to prevent excessive reinvasion by sagebrush (more than 10,000 plants per 0.4 ha (1 acre)) and to prevent removal of more than 50 percent of the annual herbaceous growth (by weight).

9. Species of sagebrush and their value to grouse need to be identified prior to burning. Some subspecies, such as *vaseyana*, may invade an area immediately after a burn and may not be as desirable for grouse as the original species or subspecies (Harniss and Murray 1973).

### CREATION OF LEKS

It has been demonstrated that new leks may be established to replace traditional leks that have been destroyed by land use activities (Eng et al. 1979, Tate et al. 1979). Establishment of new leks should be attempted after such factors as proximity of nesting, brood-rearing, and wintering areas are considered. The relationship of a new lek to wintering areas is probably the most critical factor (Eng et al. 1979). Sage grouse may move more readily to a satellite lek where at least a few birds have strutted in past years (Tate et al. 1979). See Autenrieth et al. (1981) for information about mitigating losses of habitat for sage grouse caused by mining operations and other industrial developments.

### Summary

Wildlife habitat has been a byproduct of management to enhance production of livestock on most rangelands. As demands continue to grow for a greater mix of products from rangelands, it is obvious that such cliches as "good range management is good wildlife management" will no longer suffice (Maser and Thomas 1983), certainly not for sage grouse. Pressure for increased production of livestock and other amenities is accompanied by growing public concern for wildlife. Ultimately, sage grouse can benefit from range management activities, but only if their welfare is planned in advance and their habitat requirements are no longer left to chance.

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# Appendix

## COMMON AND SCIENTIFIC NAMES

Common name	Scientific name
SHRUBS <sup>1</sup>	
Basin big sagebrush	<i>Artemisia tridentata tridentata</i>
Big sagebrush	<i>Artemisia tridentata</i>
Black greasewood	<i>Sarcobatus vermiculatus</i>
Black sagebrush	<i>Artemisia nova</i>
Bolander silver sagebrush	<i>Artemisia cana bolanderi</i>
Cleftleaf sagebrush	<i>Artemisia arbuscula thermopola</i>
Low sagebrush	<i>Artemisia arbuscula</i>
Mountain big sagebrush	<i>Artemisia tridentata vaseyana</i>
Mountain silver sagebrush	<i>Artemisia cana viscidula</i>
Willow	<i>Salix</i> sp.
Wyoming big sagebrush	<i>Artemisia tridentata wyomingensis</i>
Threetip sagebrush	<i>Artemisia tripartita</i>
GRASS	
Crested wheatgrass	<i>Agropyron cristatum</i>
FORBS	
Alfalfa	<i>Medicago sativa</i>
Aster	<i>Aster</i> sp.
Clover	<i>Trifolium</i> sp.
Common dandelion	<i>Taraxacum officinale</i>
Common salsify	<i>Tragopogon dubius</i>
Phlox	<i>Phlox</i> sp.
Prickly lettuce	<i>Latuca serriola</i>
Western yarrow	<i>Achillea lanulosa</i>

<sup>1</sup>From Garrison et al. (1976).

Common name

Scientific name

### INSECTS

Beetles

*Coleoptera*

Ant

*Formica* sp.

### BIRDS<sup>2</sup>

Common crow

*Corvus brachyrhynchos*

Falcon

*Falco* sp.

Magpie

*Pica* sp.

Great horned owl

*Bubo virginianus*

Common raven

*Corvus corax*

Sage grouse (western)

*Centrocercus urophasianus urophasianus*

Sage grouse (eastern)

*Centrocercus urophasianus phaios*

### MAMMALS<sup>3</sup>

Badger

*Taxidea taxus*

Domestic cattle

*Bos taurus*

Domestic sheep

*Ovis aries*

Richardson ground squirrel

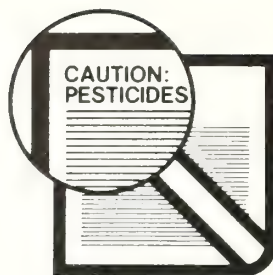
*Spermophilus richardsoni*

Ground squirrel

*Spermophilus* sp.

<sup>2</sup>From American Ornithologists' Union (1957, 1973).

<sup>3</sup>From Hall (1981).



This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

**CAUTION:** Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife – if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.



**WILDLIFE HABITATS IN MANAGED RANGELANDS—THE  
GREAT BASIN OF SOUTHEASTERN OREGON**

**Technical Editors**

**JACK WARD THOMAS, U.S. Department of Agriculture,  
Forest Service**

**CHRIS MASER, U.S. Department of the Interior,  
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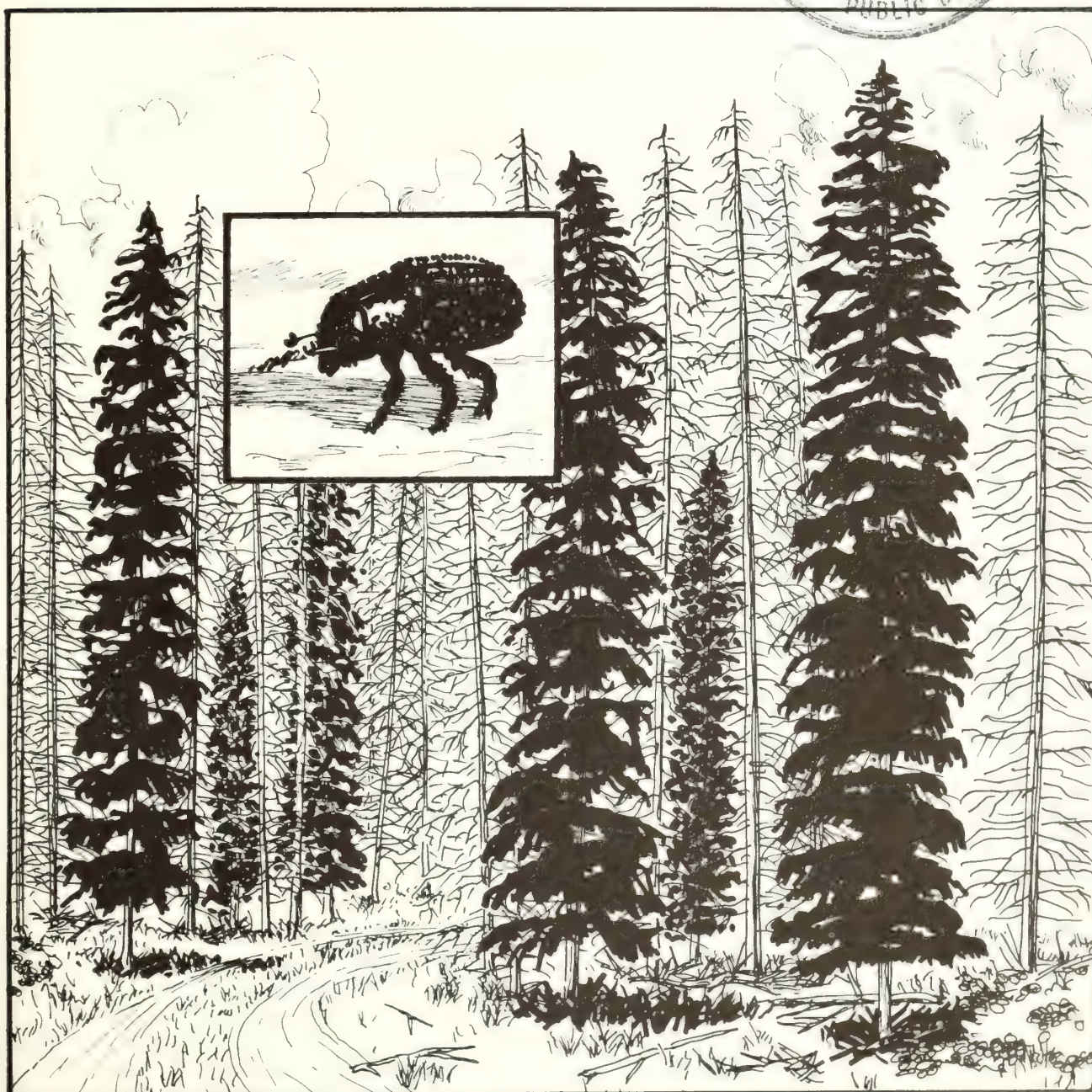
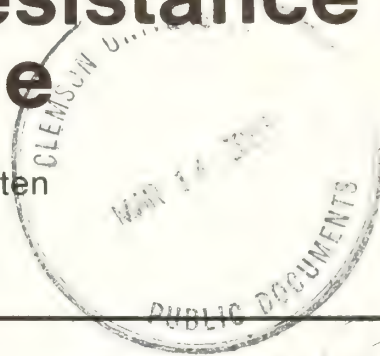
General Technical  
Report  
PNW-188

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# Managing White and Lutz Spruce Stands in South-Central Alaska for Increased Resistance to Spruce Beetle

John S. Hard and Edward H. Holsten





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## Abstract

**Hard, John S.; Holsten, Edward H.** Managing white and Lutz spruce stands in south-central Alaska for increased resistance to spruce beetle. Gen. Tech. Rep. PNW-188. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985**. 21 p.

Thinning is recommended for maintaining vigorous tree growth to minimize losses caused by spruce beetles (*Dendroctonus rufipennis* Kirby) and windthrow in residual stands of spruce in south-central Alaska. The anatomy of conifer stems, the variation in stem diameter growth, and the variability of tree response to wounding are discussed to explain why trees become vulnerable to attack by bark beetles. A working hypothesis, that beetle-attack patterns on the lower bole of trees have evolved to take advantage of the weak defense of a stressed tree, is presented as a rationale for maintaining vigorous tree growth.

**Keywords:** Thinning (-insect control, tree vigor, stand improvement, insect control, spruce, spruce beetle, south-central Alaska.

## Summary

The spruce beetle (*Dendroctonus rufipennis* Kirby) is the primary tree-killing insect in Alaska and is prevalent south of the Alaska Range. Preferred hosts are white spruce (*Picea glauca* (Moench) Voss), Lutz spruce (*P. x lutzii* Little), and Sitka spruce (*P. sitchensis* (Bong.) Carr.). Black spruce (*P. mariana* (Mill.) B.S.P.) is rarely attacked.

Ornamental spruce and high-value trees in campgrounds and administrative sites can usually be protected from spruce beetle by lightly fertilizing annually and by watering during dry periods, or by applying insecticide to the trunk. These treatments are too costly for forest stands, so silvicultural treatments are required to maintain resistance to spruce beetle attack.

Clearcutting followed by natural or artificial stand regeneration is the logical alternative for overmature stands in areas where timber management is the desired objective and temporary denudation of the site is considered environmentally acceptable. In areas where watershed protection, wildlife habitat, and recreation or esthetics would be adversely affected by clearcutting in blocks as large as 10 to 15 acres (4 to 6 ha), smaller clearcuts and partial cuts may be used.

Mature stands that are lightly infested by spruce beetle or are not infested should be harvested to a residual basal area of 60 to 120 square feet per acre (14 to 28 m<sup>2</sup>/ha) depending on site quality. Residual trees should be free from defects, firmly rooted and with vigorous crowns, and growing radially at a rate of about 1/2 to 1 millimeter or more in the last complete annual ring. Residual trees should be released from competition on at least three sides but not spaced so widely that substantial snowbreakage and windthrow are likely to occur.

Partial cutting can also be accomplished by clearcutting narrow strips of timber at right angles to prevailing winds, alternated with wider residual strips thinned according to principles mentioned above. Clearcut strips should be wide enough for skidders to pass, and residual timbered strip width should be twice the length of skidder cables so skidders can operate from outside the residual stand. Stands thinned in the manner proposed should be relieved of serious competition for soil moisture except during extreme droughts. Damage to residuals caused by harvesting will be minimized, and the stands should be comparatively windfirm.

Trees must be relieved from serious competition for moisture in late May and June if their resistance to spruce beetle attack is to be effective. Spruce beetles concentrate attacks in June in the lower tree bole which is farthest from the source of growth hormones and photosynthates produced in the crown. These materials are required with water for cambial cells to divide. Resistant trees respond initially to beetle attack with a copious flow of resin from existing resin ducts in the bark cortex, the phloem, and the xylem. Resin-producing cells surrounding these ducts must be hydrated to maintain positive resin pressure within the ducts and photosynthates are required for the cells to produce more resin when ducts are ruptured. Initial resinosis often causes beetles to abort their attacks.

The secondary response of trees to attack is delayed and consists mainly of formation of wound periderm and more horizontal resin ducts in the phloem and bands of longitudinal resin ducts in the xylem adjacent to cambium above and below the beetle gallery. This formation of "traumatic tissue" and the production of additional resin inhibit survival of beetle larvae in the phloem and spread of water-blocking "blue-stain" fungus into the xylem.

Trees under moisture stress reduce photosynthesis and translocation of growth substrates to stem cambium. Supplies of these materials required for cambial cell division can be limited in the lower boles of trees with high-setting crowns in dense stands because of distance from the active crown and utilization by branch and stem cambial tissue farther up the bole. Shortage of growth substrates from the crown, in addition to reduced hydration of cambial cells, inhibits cell division, resin production in existing ducts, and formation of new resin ducts and resin in response to beetle attack.

Conversely, open-grown trees with long effective crowns are rarely exposed to moisture stress for extended periods except when flooded or during extreme droughts. Radial growth is comparatively rapid in the lower bole because requirements for cambial cell division are rarely limiting there. Such trees are typically more resistant to bark beetle attack unless they are suffering from some other physiological disorder such as infection by pathogenic root fungi.

We hypothesize that concentrations of spruce beetle attacks on the lower bole of spruce have evolved to take advantage of the limited response in the lower bole of the tree under moisture or nutrient stress. Apparently, requirements for rapid stem radial growth are the same as for vigorous primary and secondary resin responses to wounding in the stem cambium. Therefore, rapidly growing trees are more likely to respond vigorously to bark beetle attack than are slowly growing trees.

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## Introduction

The spruce beetle (*Dendroctonus rufipennis* Kirby) is a major killer of spruce across Canada and from the southern Rocky Mountains to Alaska (Safranyik and others 1981, Schmid and Frye 1977, Werner and others 1977). Its primary hosts are Engelmann spruce (*Picea engelmannii* Parry ex Engelm.) in the Rocky Mountains and white spruce (*P. glauca* (Moench) Voss) in Alaska. It also attacks the maritime species, Sitka spruce (*P. sitchensis* (Bong.) Carr.), and Lutz spruce (*P. x lutzii* Little), the hybrid of white and Sitka spruce which occurs extensively on the Kenai Peninsula (Copes and Beckwith 1977, Little 1953). Black spruce (*P. mariana* (Mill.) B.S.P.) may occasionally be attacked, but it does not support spruce beetle outbreaks and is also the least preferred host of spruce beetle in eastern Canada (Morris 1958).

Beetle outbreaks often begin where there is abundant breeding material such as dead or dying trees and slash (Schmid 1977). This material often results from fire, windstorms, land clearing, and logging. Live trees weakened by drought, flooding, defoliation, root disease, root compaction, or advanced age are also susceptible to attack by bark beetles. But outbreaks have begun in mature stands where these classical, preoutbreak conditions are absent. For example, Morris (1958) stated that in the Maritime Provinces of eastern Canada outbreaks often began in over-mature stands, and beetles often concentrated their attacks on larger, slowly growing trees. In one large outbreak, 80 percent of trees killed were over 10 inches (25 cm) in diameter; and in another outbreak, before they were killed trees had been growing only 63 percent as fast as trees not attacked.

Knowledge about spruce beetle and its hosts, although far from complete, parallels much of what is known of other bark beetles and their respective hosts. We emphasize the defensive responses of a tree to wounding because they appear to be directly related to current growth rate (Pitman and others 1982) which can be manipulated through standard forestry practices. We also emphasize interactions between bark beetles and trees at the beginnings of outbreaks because they show how stands can be manipulated to prevent outbreaks in areas where high mortality of trees is not acceptable.

For stands that are not infested or are lightly infested by spruce beetle, we recommend procedures that should restrict future losses of trees to tolerable limits within accessible areas where wildfire, watershed protection, wildlife habitat, and the esthetic value of green stands are important public concerns.

## Recommendations for Increasing Resistance of Spruce to Spruce Beetles

Vigor of high value spruce in campgrounds and administrative sites can usually be maintained by adequate watering during dry periods, by light applications of fertilizer at intervals of 1 to several years, or by spacing trees to reduce competition for soil moisture. If the sites are adjacent to dense spruce stands that harbor outbreak populations of spruce beetle, then tree boles of high value trees can be protected by annual or biannual applications of insecticide (Werner and others 1984). But such individual-tree treatments are expensive, and cost-benefit ratios are economical only for trees of very high value. Therefore, silvicultural manipulations are probably necessary to protect stands containing numerous trees from spruce beetle attack.

Pure spruce stands that are considered overstocked and mixed stands that are growing slowly as a result of apparent competition should be logged if high mortality resulting from spruce beetle attack is undesirable. If such stands are substantially more than a 120- to 150-year rotation age, depending on site quality (Eis and others 1982), clearcutting in 10- to 15-acre (4- to 6-ha) blocks followed by natural or artificial regeneration may be the most logical management option.

If timber production is not the selected management alternative, but maintenance of standing green timber for wildlife and watershed protection or esthetic purposes is desired, then partial cutting may be the appropriate management option even in stands well over 100 years old. White spruce is a relatively long-lived species and may live for 250 to 300 years on productive forest sites (Sutton 1969) and even for 500 to 1,000 years at high elevations and high latitudes (Giddings 1962). We have observed dominant spruce as old as 240 years at breast height (bh) with growth that had recently accelerated and that had recently survived spruce beetle attack.

When mature stands are thinned to reduce susceptibility of residuals to spruce beetle attack, all residuals must be released from competition to stimulate growth to measurable levels in the lower tree boles. Retaining some widely spaced individuals and clumps of closely spaced individuals defeats our purpose because the closely spaced individuals may elicit little if any growth response, and ability to survive spruce beetle attack will probably remain low. Natural clumps of trees with spacing wide enough that little or no competition exists among them will not require release.

Partial harvesting could also be accomplished by clearcutting narrow strips at right angles to the prevailing winds and then by releasing trees within the residual timbered strips. Residual timbered strips should be no wider than twice the length of a skidder cable, and clearcut strips bordered by expendable "bumper" trees should be just wide enough for harvesting machinery to pass. This procedure should provide windfirmness of residuals and should reduce damage to residuals from felling and skidding operations.

We propose that uninfested or lightly infested spruce stands selected for partial cuts to reduce susceptibility to additional spruce beetle attack have their basal areas reduced to 60-120 square feet per acre (14-28 m<sup>2</sup>/ha) in the following manner:

1. Mark all spruce trees 14 inches (36 cm) or larger in diameter for removal regardless of growth rate.
2. Select and mark plainly for reference 10- to 12-inch (25- to 30-cm) diameter "leave" spruce trees that have straight stems free of defect, live-crown ratios of 40 percent or more, radial growth rates of 1 millimeter or more in the last complete annual ring at breast height, and that appear to be firmly rooted. When selecting trees for retention avoid trees with crowns confined to one stem quadrant or that are flat topped, and avoid trees growing on potentially moisture-stressing microsites (such as waterlogged depressions or small, sharp ridges or hummocks formed between former erosion channels). Some trees of these undesirable types located at strategic points along skidding trails should be designated as bumper trees to prevent damage to leave trees; they should be marked to be felled and removed last.

3. From the 8- to 10-inch-diameter (20- to 25-cm) codominants and intermediates around each of the initial selected leave trees, select additional smaller trees with the last complete annual ring 0.5 millimeter wide or wider and with well-formed crowns and sound stems. The lower radial growth rate of these smaller trees approximates the same percentage of basal area growth as of the larger leave trees. Make sure that each of the primary and the secondary leave trees will be released on at least three sides during harvest. Selection of residuals by growth rate should result in wider spacing and lower residual basal areas on unproductive sites than on productive sites.
4. Fell all the remaining trees except bumper trees in April, May, June, and early July; use chainsaws instead of tractor-mounted shears to minimize damage to the residuals; and allow the felled trees and logs to absorb beetles in the area.
5. Postpone skidding until after beetle flight, which occurs from late May through June, and after tree cambial activity has slowed in mid-July to late July. This will allow for "capture" and removal of the beetle population, it will minimize skidding damage to residuals because bark will not "slip" as easily after cambial growth has slowed, and it will eliminate skidder-caused damage to soils when they are wettest.
6. Fell and remove bumper trees last.
7. Process or chemically treat logs at the mill before the next May to avoid local beetle infestations if there are spruce stands nearby.

If spruce are desired as residuals in mixed stands, the better spruce should be released in a similar manner by removing adjacent trees of the other species. Removing the better spruce and retaining the other species, which may be a management alternative, could essentially remove the site from spruce production permanently, however, unless it is clearcut and planted to spruce.

Based on what we have seen in natural stands with various growth rates and stocking levels, stands treated in the manner suggested should experience increased soil temperatures, increased soil-to-tree moisture flow, reduced internal tree moisture stress, and increased growth rates. As a result, modified stands should be substantially more resistant to outbreaks of spruce beetle, and the residual stand should be comparatively windfirm (MacDonald 1963). In addition, stand treatments can be partially paid for by sale of harvested saw logs, house logs, and firewood.



## Relationship of Stand Stocking to Tree Growth and Bark Beetle Attack

Thinning to reduce tree losses caused by bark beetles is commonly recommended in cases of other conifer hosts, but primarily for stands approaching maturity or stands younger than rotation age (Shrimpton and Thomson 1983). Initially, residual trees may experience "thinning shock" before soils are recharged with moisture or before root systems have expanded because the crowns are exposed to more sunlight and air movement which may increase loss of water by transpiration (Whitehead and Jarvis 1981). This condition, although short lived, could temporarily increase susceptibility of residuals to bark beetle attack because of stress, but growth normally improves rapidly because of reduced tree competition.

Larsson and others (1983) thinned ponderosa pine (*Pinus ponderosa* Laws.) which resulted in increased growth of residuals and reduced loss of trees to mountain pine beetle (*D. ponderosae* Hopkins) attack. McCambridge and Stevens (1982) showed that Black Hills ponderosa pine stands thinned to less than 90 square feet per acre (21 m<sup>2</sup>/ha) basal area experienced low mortality caused by mountain pine beetle, whereas mortality rates in adjacent unthinned stands continued.

Sartwell and Stevens (1975) reported similar results in eastern Oregon stands where ponderosa pine poletimber was thinned to basal areas of 117, 86, 62, and 35 square feet per acre (27, 20, 14, and 8 m<sup>2</sup>/ha), but mortality caused by mountain pine beetle was higher in an unthinned plot with initial basal area of 173 square feet per acre (40 m<sup>2</sup>/ha).

Mitchell and others (1983) reported that nine lodgepole pine (*P. contorta* Dougl.) stands in eastern Oregon, heavily thinned to an average basal area of 53 square feet per acre (12 m<sup>2</sup>/ha), experienced an average of about 4 percent mortality from mountain pine beetle attack, whereas four stands lightly thinned to an average basal area of 117 square feet per acre (27 m<sup>2</sup>/ha) averaged 21 percent. Unthinned stands with an average basal area of 191 square feet per acre (44 m<sup>2</sup>/ha) experienced an average of 19 percent beetle-caused mortality. Low losses in heavily thinned stands were attributed to increased growth of residuals.

Belanger [n.d.] recommends that overstocked southern pine stands be thinned to basal areas of 80 to 100 square feet per acre (18 to 23 m<sup>2</sup>/ha) to reduce risk of southern pine beetle (*D. frontalis* Zimmerman) attack, but that stands in areas subject to severe wind and ice storms should not be thinned too heavily. High winds and heavy snows are common causes of tree fall or top breakage of spruce (Van Cleve and Zasada 1970), particularly in south-central Alaska, so similar caution should be taken in Alaska stands to prevent loss of residual trees that would probably become breeding material for spruce beetle. Spacing trials of 50- to 60-year-old spruce in interior Alaska by University of Alaska personnel resulted in 45-percent breakage caused by snow in stands thinned to 16- by 16-foot (4.9- by 4.9-m) spacing; 25 percent in stands thinned to 12- by 12-foot (3.7- by 3.7-m) spacing, and 0 percent in unthinned stands.<sup>1/</sup>

<sup>1/</sup>Personal communication with John Zasada, Research Forester, Forestry Sciences Laboratory, 3200 Jefferson Way, Corvallis, Oregon 97331.

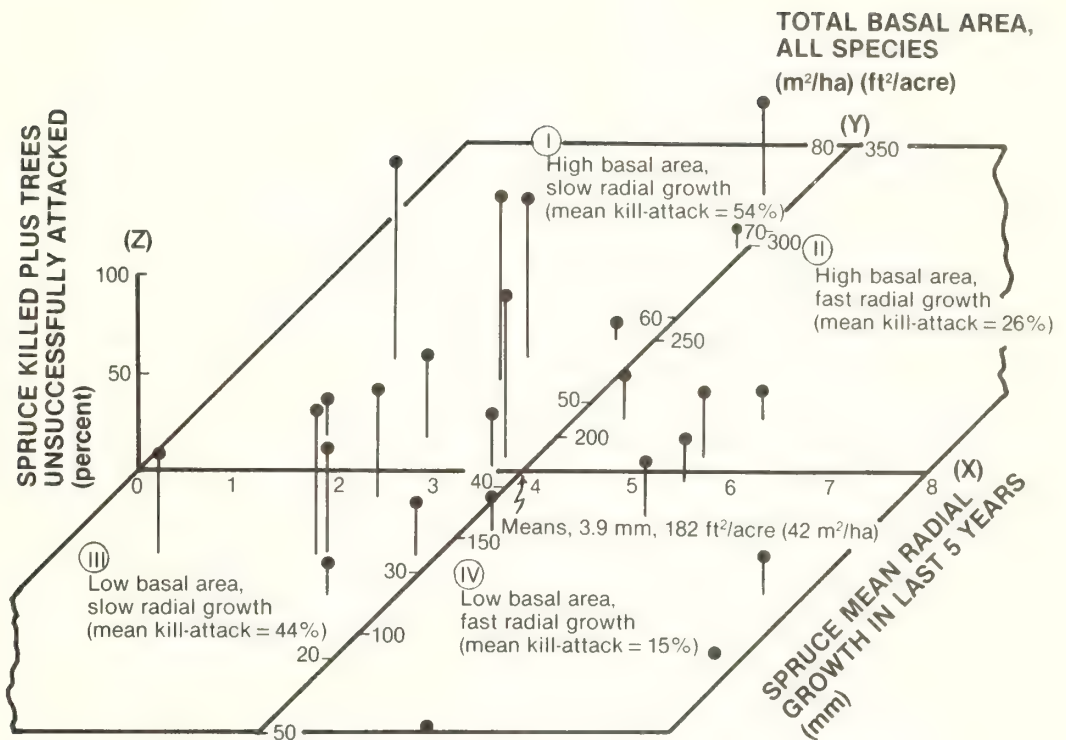


Figure 1.—Percentage of trees killed by spruce beetle and unsuccessfully attacked spruce (Z) on 25 variable-radius plots during the early years of an outbreak versus mean radial growth of spruce (X) and total stocking of all tree species (Y). The graph is divided into quadrants based on intersection of the (X) and (Y) axes at their means. Vertical lines extending below plotted points indicate elevations of points above the (X,Y) plane.

Frank (1973) determined that significant growth response in thinned 70-year-old white spruce required that residuals be released on more than two sides, and that the number of days that a tree grew during a season increased with degree of release. Trees released on three or four sides grew almost twice as rapidly the next 10 years as trees released on only one or two sides. Trees released on four sides started growth earlier and ceased growth later each year than trees released on three sides or less.

Van Cleve and Zasada (1976) fertilized and thinned 70-year-old white spruce in interior Alaska from 174 to 70 square feet per acre (40 to 16 m<sup>2</sup>/ha) basal area. Soil moisture increased significantly, soil temperatures increased moderately, and basal area increment after 5 years was twice as high in thinned stands as in unthinned stands. There was no evidence of thinning shock, and growth accelerated the year after treatment.

Slowly growing mature spruce in heavily stocked stands near Summit Lake on the Kenai Peninsula had higher than average losses after spruce beetle attack (fig. 1). Stands growing faster than average (quadrants II and IV) had substantially lower spruce beetle attacks and tree mortality than slowly growing stands (quadrants I and III). The more heavily stocked stands shown in quadrants I and II sustained

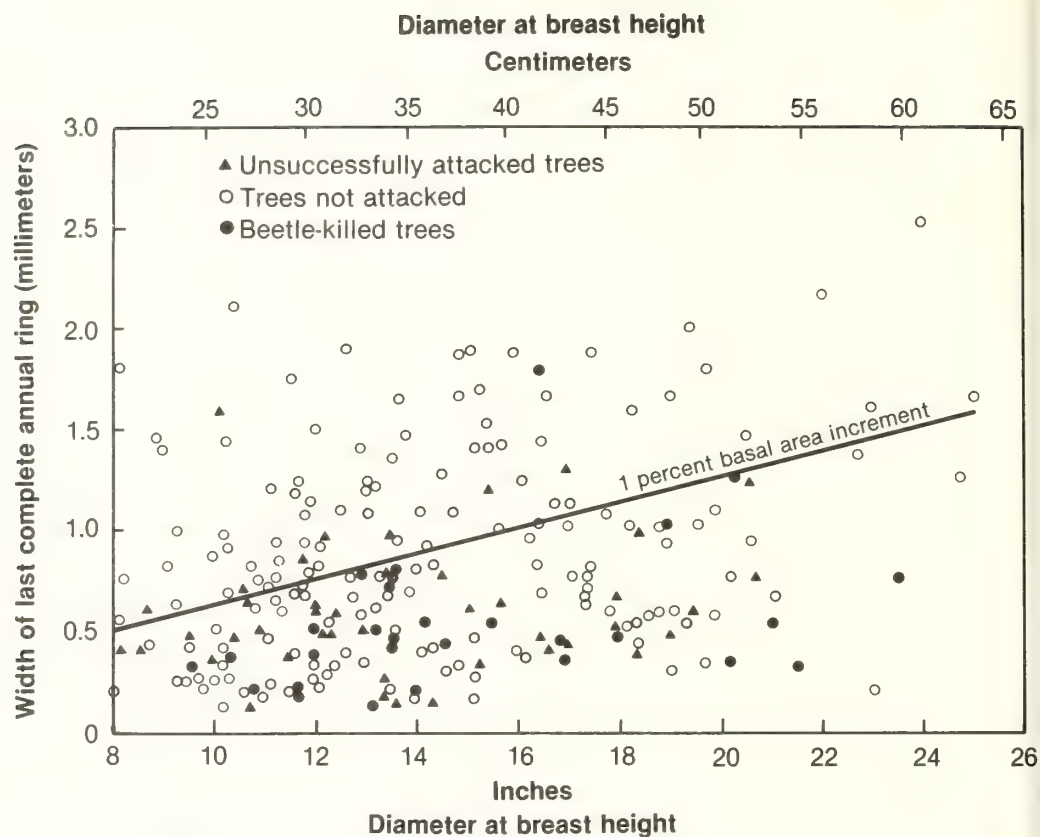


Figure 2.—Relationship of radial growth to diameter of trees in the year before spruce beetle attack, by tree condition class on the 25 variable-radius plots shown in figure 1. The ascending line intersects the ring width required for a tree of given diameter to grow at a basal area increment rate of 1 percent, if bark thickness is assumed to equal zero.

greater average damage than did the more lightly stocked stands in quadrants III and IV which were growing at comparable rates to quadrants I and II, respectively. Damage caused by spruce beetles was highest in quadrant I in heavily stocked stands growing more slowly than average. Average attack and mortality were 10 percent less in lightly stocked, slowly growing stands in quadrant III, followed by greater reductions in quadrants II and IV.

These patterns of damage show that stands characterized by fast growing rates and low stocking levels (quadrant IV) were least susceptible to spruce beetle during early years of the outbreak, and that heavily stocked stands still growing rapidly (quadrant II) were less susceptible to attack than lightly stocked stands that were growing more slowly (quadrant III).

Growth in dense stands and in lightly stocked stands on very poor sites is often reduced because carbohydrates for stem growth are limited after demands for respiration and leaf formation are satisfied (Smith 1962). Limited carbohydrate reserves exemplified by slow radial growth may also reduce the ability of trees to respond defensively to spruce beetle attack. For example, when radial growth for the last complete annual ring of individual sample trees is plotted over tree diameter (fig. 2), it becomes readily apparent that basal area increment the year



## Spruce Beetle Attack and Tree Response

before beetle attack was less than 1 percent of tree basal area for 57 percent of trees that were not attacked, for 80 percent of the unsuccessfully attacked trees, and for all but one of the killed trees.

To produce young the spruce beetle must kill its host tree, or a portion of the tree. Beetles can apparently sense stressed trees (Safranyik and others 1981), and in south-central Alaska they concentrate their attacks in June, which comprises the first half of the period of rapid cambial growth for interior Alaska white spruce (Gregory 1971). In some years, attack density peaks before soils have completely thawed,<sup>2/</sup> and the cold soils may cause tree moisture stress (Kaufmann 1975) during initial growth.

The beetles carry spores of "blue-stain" fungi, and the trees are inoculated with these fungi during beetle attack. This fungal growth assists the beetles in killing the host by spreading into the sapwood, blocking the tracheids, and stopping water transport from roots to crown (Whitney 1982). Trees with only a portion killed by attacking beetles have a narrow vertical strip of killed cambium, called "strip kill" or "strip attack." They are not as abundant as trees killed outright by the bark beetles but are not uncommon during outbreaks.

Spread of blue-stain fungi in the bole is mainly radial and vertical (Safranyik and others 1975), and limited circumferential spread accounts for strip kills when only one side of a tree is successfully attacked. Stem vigor index is commonly less on the strip-killed side of the tree in lodgepole pine and often coincides with the side of the tree with spare crown (Pitman and others 1982).

Spruce beetles preferentially attack and kill large diameter trees that have been growing slowly at breast height (Hard and others 1983, Hard 1985, Morris 1958, Watson 1928). These trees are often dominants or codominants in well-stocked stands (Schmid and Frye 1976), but many uncrowded large diameter dominant and codominant trees still growing rapidly are attacked and not killed. Radial growth analysis of trees in the outbreak referred to by figures 1 and 2 shows that sampled trees of all classes grew more rapidly from 1967 through 1971 than from 1972 through 1978 (fig. 3). Trees killed in 1980 and 1981 grew slowly after 1973, and trees attacked in 1981 but not killed accelerated only slightly in growth after 1975. In contrast, unattacked trees larger than 9.5 inches (24.1 cm) in d.b.h. not only grew more rapidly than the others before 1973 but also accelerated more rapidly in growth after 1975.

The spruce beetle concentrates its attacks on the lower tree bole (fig. 4) (Knight 1960), as does the mountain pine beetle on lodgepole pine (Klein and others 1978, Rasmussen 1974). The first-arriving mountain pine beetles ("pioneers") attack the lower boles of lodgepole pine. If the pioneers are successful in entering the tree, they emit odors that attract other beetles; the attacks spread around the initial attack site and then up the bole (Berryman 1982). When attack densities reach a critical level, the beetles emit different odors or the tree ceases to exude resin; this signals that the tree is colonized and new arrivals are repelled (Raffa and Berryman 1983). Therefore, newly arriving beetles may attack nearby trees instead (Geiszler and Gara 1978).

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<sup>2/</sup> Spruce beetle attack relative to host phenology and host vigor index. Unpublished report by John S. Hard on file at the Institute of Northern Forestry, Fairbanks, Alaska 99775-5500.

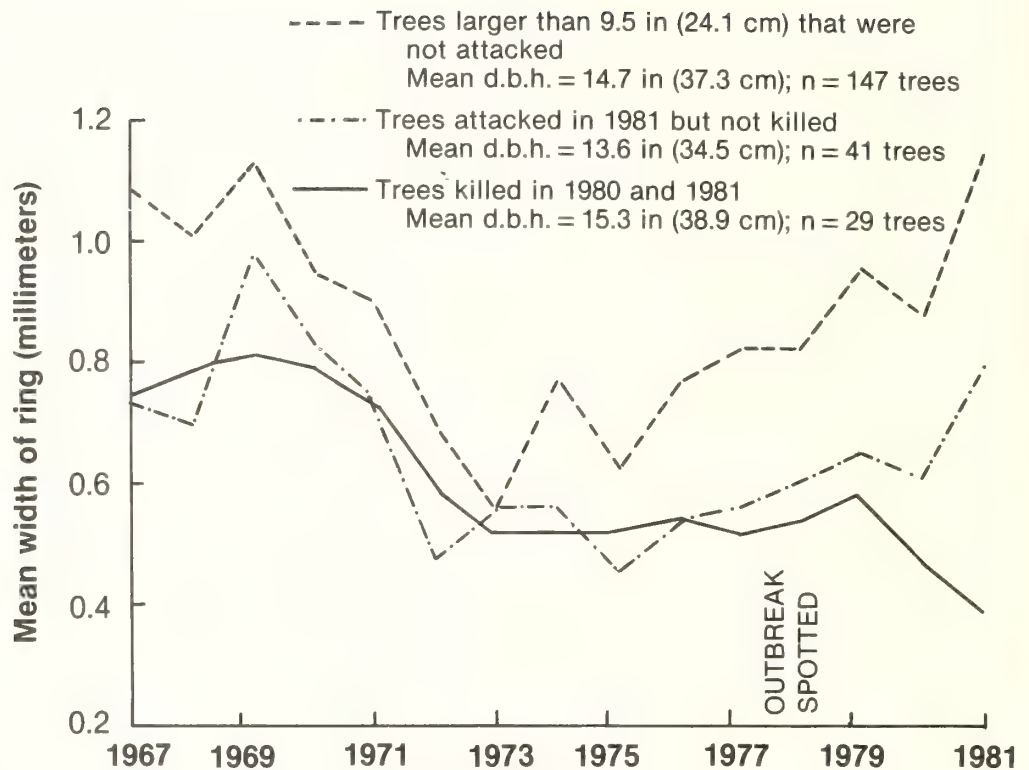


Figure 3.—Mean annual radial growth at breast height from 1967 to 1981 by tree condition class. Deflection of radial growth in the final year for trees killed by spruce beetle is probably caused by trees dying before the end of the growing season.

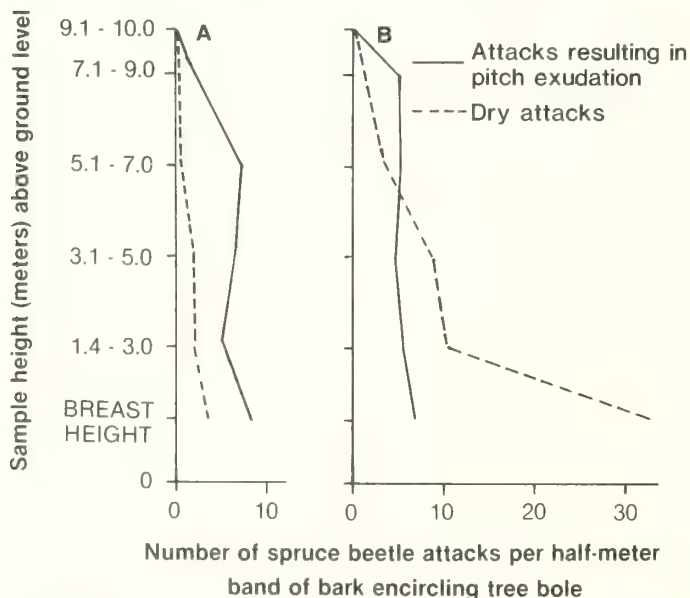


Figure 4.—Height distribution of spruce beetle attacks below live crown in 1984 in a 100-year-old densely stocked stand. A. Unsuccessfully attacked trees (n = 48). B. Killed trees (n = 16).

The initial pattern of attack on the lower bole of pine is partially due to the deep bark fissures that aid entry by the attacking beetles through the thick lower bark (Safranyik and Vithayasai 1971, Shepherd 1965). In addition, the lower bole is often below the snow line which affords protection for bark beetle broods from lethally low temperatures during extremely cold winters and from predation by woodpeckers (Schmid and Frye 1977). Perhaps the lower bole can also be considered the "Achilles heel," especially of slowly growing trees, because attacking beetles may have less chance of being repelled there by defensive reactions of the host. Attack densities were fairly uniform along the boles of unsuccessfully attacked spruce in an outbreak in Alaska, and most attacks resulted in a resinous response from the host (fig. 4). Conversely, killed trees were attacked most heavily on the lower bole, and most attacks there were nonresinous whereas the majority of attacks in the upper bole still elicited a resinous response.

Horizontal phloem resin ducts proliferate near bark wounds, and some spruce respond to attack with a profuse flow of resin from an already existing network of vertical ducts in the bark cortex outside the phloem and horizontal unconnected ducts in the phloem and xylem rays (Thomson and Sifton 1925). Spruce also form tangential bands of longitudinal xylem resin ducts or "traumatic tissue" at the cambium adjacent to the wound.

Resin formed in the epithelial cells of parenchyma tissue is secreted to areas between the cells which forces them apart to form an elongated, cylindrical, resin-filled cavity called a resin duct. The duct widens quickly and may reach maximum diameter before adjacent tracheid walls are completely developed.

Bands of vertical ducts become dispersed above and below the wound but are usually confined to the same annual ring in spruce. These ducts may reach more than 2 feet (60 cm) in length and generally increase in number with cambial age. The increase is probably due partially to an increased number of injuries incurred by the lower tree stem, but the proportion of functional thin-walled epithelial cells surrounding resin ducts is higher in outer rings of the lower bole, and for a given wound size the number of traumatic resin ducts formed tends to increase as ring width increases (Bannan 1936). This occurs probably because a wider band of active cells in the cambial zone and a greater number of cambial cell divisions occur in spruce with wide annual rings (Gregory and Wilson 1968, Gregory 1971).

Vité (1961) believed that trees became susceptible to bark beetle attack when transpiration from the crown and water absorption into the tree were unbalanced, which resulted in decreased turgidity of epithelial cells lining the resin ducts and in reduced exudation of resin. Wounded white spruce seedlings formed resin ducts only when cambial cell division was occurring and formation ceased when radial growth ceased because of moisture stress; density of resin ducts formed in seedlings relieved of moisture stress was lower than in seedlings that were never moisture stressed (Safranyik and others 1981). Turgid epithelial cells in fully hydrated trees exert pressure on the duct so resin is forced out into the wound when the duct is damaged (Bannan 1936). Therefore, even if the initial response of a tree is inadequate to prevent the attacking beetles from laying eggs, larvae and blue-stain fungi will probably encounter newly formed ducts in the cambium or additional ducts in the phloem and may be killed by heavy resinosis if stem tissues are fully hydrated.



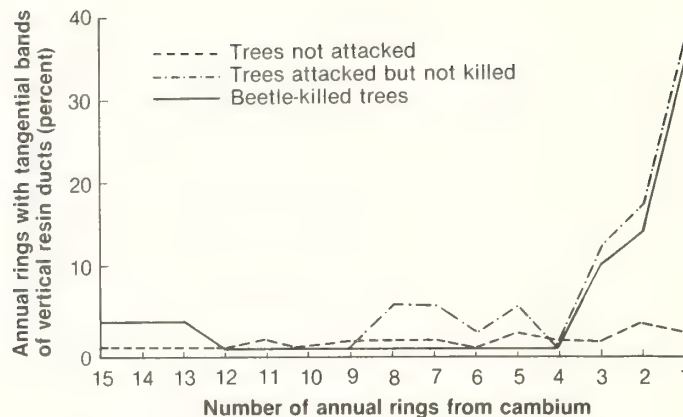


Figure 5.— Percentage of “traumatic” resin ducts in spruce increment cores by tree damage class and annual ring. Cores were collected in 1981 from an area on the Kenai Peninsula where a spruce beetle outbreak appeared in 1978.

Berryman (1976) showed that in lodgepole pine, resin ducts in the bark cortex increased in density and size with height on the bole but that they occurred abundantly as far down as the root collar on younger trees. Beetles attacked a longer section of bole in nonresistant trees, and limited resinosis followed the attack, whereas more abundant attacks concentrated near the base of the tree were required to kill resistant trees.

The disparity in spatial arrangement of attacks between nonresistant and resistant trees suggests that beetle behavior has also evolved to take advantage of a gradient of tree response to attack. Metabolic activity tends to be lowest near the base of tree stems (Larson 1962, 1963), and rate and seasonal duration of radial growth in suppressed pine were greater in the upper stems than in the lower stems which emphasizes recurrent deficiency in metabolites in lower stems (Kozlowski 1964). Metabolic activity that contributes to resinosis is apparently not constant along the bole because inoculation of resistant lodgepole pine at various stem levels with blue-stain fungus resulted in an increased response up to 18 feet (5.5 m) and a diminished response higher up (Reid and Shrimpton 1971).

Tangential bands of traumatic resin ducts seen in increment cores extracted from trees attacked by spruce beetles indicate that some trees are attacked repeatedly before they are finally killed (fig. 5). Traumatic resin ducts first appeared in significant numbers in the eighth annual ring from the cambium, which probably coincides with the beginning of spruce beetle attacks on live trees within that particular infestation.

### Effects of Reduced Water and Growth Substrates on Stem Diameter Growth

Stemwood is composed primarily of longitudinal cells called tracheids. Water is transferred between tracheids through thin-walled, membranous connections called pits that are normally concentrated on the radial, overlapping tracheid surfaces (Zimmerman 1983). In heartwood the pits have become aspirated or closed to the passage of water and the tracheids are occluded (Brown and others 1949). The sapwood is the primary pathway for transport of water from roots to crown (Kozlowski 1968), so the cross-sectional area of the sapwood is proportional to tree crown size (Grier and Waring 1974).

Each annual ring is composed of early wood and late wood. Transition from production of early wood to late wood, associated with cessation of shoot elongation and reduced production of growth hormones, begins annually in the lower bole (Larson 1962, 1963). Water is transported within the sapwood mainly through the large-diameter early wood tracheids; the smaller diameter, thick-walled tracheids in the late wood, which have fewer and smaller pits than early wood tracheids, are essentially nonconductors (Whitehead and Jarvis 1981, Kozlowski 1968). Natural aspiration or functional sealing of pits within the early wood tracheids increases from the cambium toward the heartwood in many conifers, so water transport is concentrated in the outermost sapwood rings, the zone of least resistance (Kozlowski 1971).

Carbohydrates and growth hormones produced in the foliage, necessary for cambial cell-division in the stem, are transported downward from the foliage through sieve cells in the phloem between the cambium and bark cortex (Crafts and Crisp 1971, Zahner 1963). The portion of phloem actively involved in translocation is a very narrow band of cells and is only a fraction of a millimeter thick (Abbe and Crafts 1939). Its sieve cells must be mature for rapid translocation of growth substances to occur (Crafts and Crisp 1971), and they are functional for only two seasons in spruce (Gregory 1971). The number of phloem cells formed radially from the cambium each season is a constant proportion of the number of xylem cells formed (Gregory 1971, Grillo and Smith 1959); therefore, narrower xylem rings are accompanied by narrower annual phloem rings as radial growth slows.

The primary cause of reduced tree growth is diminished water supply to the crown (Whitehead and Jarvis 1981). During transpiration, water vapor is drawn through closeable leaf pores called stomata to the atmosphere and is replaced by water stored in branches and stem. During normal and dry weather, except in very humid geographic areas, the loss of water through transpiration exceeds water uptake almost daily, but the leaf stomata close at night and the tree is recharged with moisture through the roots if soil moisture is available (Kozlowski 1968) and soil temperatures are high enough.

Soil temperatures below a critical threshold of about 1 °C for Sitka spruce and about 7.5 °C for Engelmann spruce cause low root conductivity of water and reduced water potential within the tree (Whitehead and Jarvis 1981, Kaufmann 1975). We do not know the critical soil temperature for white spruce, but soil temperatures below 10 °C resulted in increased resistance to waterflow in white spruce (Goldstein and others, in press) and reduced root elongation (Tryon and Chapin 1983). Root moisture flow is affected by the increased viscosity of water at low temperatures and by the permeability of root membranes, which varies by temperature and species (Kramer 1983).

If soil moisture is not available because of (a) low soil temperatures in the active root layers, (b) lack of recharge through precipitation, or (c) excessive competition among trees and ground vegetation during normal weather, then even the most vigorous trees will experience stress from internal water deficits. When moisture stress occurs, the leaf stomata close during daylight hours and photosynthesis is slowed. All land plants experience internal moisture stress periodically even when soil moisture is near field capacity, and in most regions soil moisture is rarely optimal during the growing season (Kozlowski 1968).



Water absorption by the roots can also be impeded if soils are waterlogged (Whitehead and Jarvis 1981, Zahner 1968). Trees are tolerant of waterlogged soils during dormancy, but actively growing root tips are very sensitive to the resulting anaerobic conditions in waterlogged soils (Coutts and Philipson 1978).

Most growth responses responsible for (a) amount and quality of photosynthates and growth hormones, (b) level of cambial activity, (c) period of tracheid growth and expansion, and (d) rate of upward waterflow through new tracheids in the current-year early wood adjacent to the cambium are governed by atmospheric conditions, transpiration rates, and variations in available soil moisture (Zahner 1963). Furthermore, moisture stress that affects growth in the current year may have a lag effect on the next year's growth because bud formation in the current year predetermines the number of needles that will be formed on shoots the following year (Kozlowski 1971). Thus, photosynthetic capacity of the next year's shoots can be diminished even if weather conditions are optimal for growth. Spruce may carry several consecutive years' complement of needles, but the greatest photosynthetic production occurs late in the season in current-year white spruce needles and throughout the season in needles 1 year old (Clark 1961).

Scattered trees in open stands usually have comparatively wide, fully active crowns, pronounced stem taper, and few self-pruned dead branches. They experience little or no competition from neighbors; and if roots are healthy, they incur serious moisture stress only during flooding and severe droughts or when air temperatures are warm and soils are very cold or are actually frozen. Trees in dense stands usually have longer, more-cylindrical boles with comparatively more dead lower branches and relatively short live crowns (Farrar 1961, Larson 1963). Much of the lower live crown is partially shaded by neighboring trees, and photosynthesis is concentrated in the upper exposed crown portions. In addition, soils are usually colder during the growing season in dense stands because sunlight is reduced at the forest floor and thick layers of undecomposed organic debris insulate soils from ambient air temperature.

For radial growth to begin in the spring, growth hormones as well as food substances must be present in the stem cambium because cell division will apparently not begin if only food substances are present. After bud break, which initiates growth hormone production, cambial activity proceeds down the bole more rapidly in open grown trees with long effective live crowns and continues longer at breast height than in trees with short, high-setting crowns in dense stands (fig. 6A).

Growth hormone requirements for cambial activity are less in the smaller total cambial surfaces of short upper branches than in longer lower branches, so the highest growth hormone levels along the stem cambium often occur near mid-crown because of surplus hormones from the upper crown. Therefore, the annual sheath of newly formed stemwood is often thicker near midcrown (fig. 6B). In some years, an annual ring that can be measured at the base of the live crown may be discontinuous or even nonexistent at breast height because growth substances are completely consumed by cambium farther up the stem. Under these circumstances cambium at breast height (fig. 6A) remains alive but dormant (Brown and others 1949). In years with better growing conditions growth substances are transported in greater quantities to the lower bole, and a wavelike increase of radial growth moves down the tree to form a wider annual ring at breast height (Larson 1962).



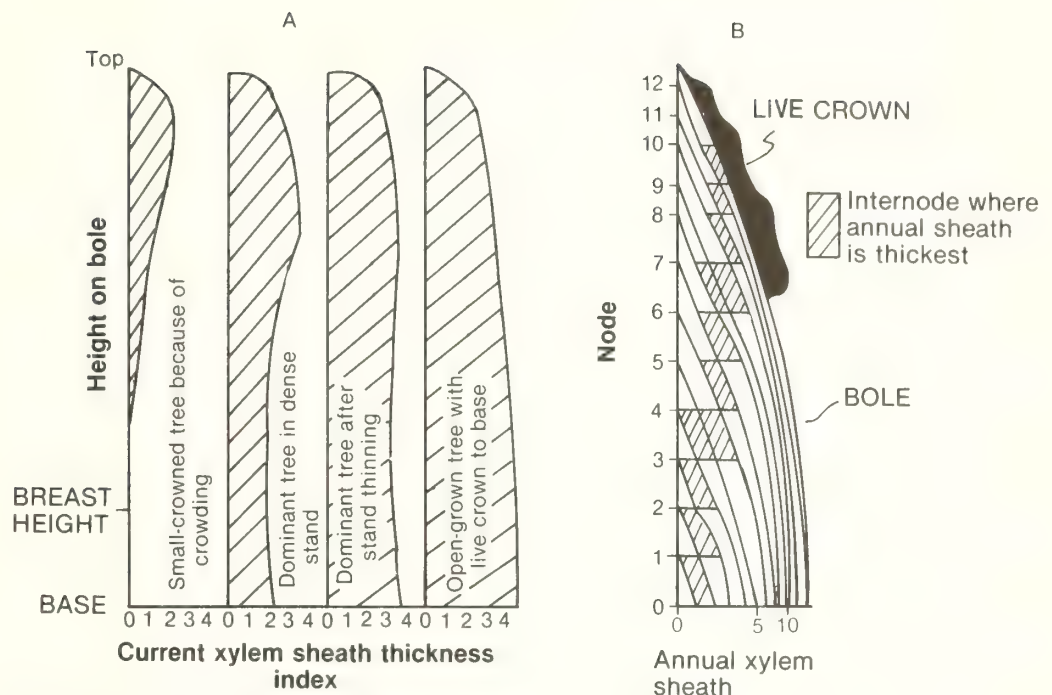


Figure 6.—Diagrams with expanded horizontal scale of hypothetical tree xylem sheath growth patterns. A. Vertical variation in width of annual sheath controlled by stand closure and size of effective crown (after Farrar 1961). B. Change in vertical position of widest part of xylem sheath relative to tree age and unfoliated length of bole (after Smith and Wilsie 1961).

Generally, good growing conditions shift the location of maximum radial growth down the stem, and unfavorable growing conditions shift the position of maximum radial growth up the stem closer to the source of growth hormones and photosynthates (Larson 1963). The position of minimum radial growth below the live crown is shifted accordingly. For example, Shrimpton and Thomson (1983) sectioned mature lodgepole pine in stands infested by mountain pine beetle to reveal radial growth patterns along the stems in the 15-year period before cutting. Location of minimum radial increment for a given year varied from one-tenth to six-tenths of stem height, but the mean height of minimum increment occurred at about one-fifth of stem height and the modal height of minimum increment was at about one-seventh of stem height.

Ultimately, mature trees will die if they are growing so slowly that growth substances produced by the crown are inadequate to support cambial activity in the lower bole. A similar process of senescence is responsible for self-pruning of lower branches in shaded crowns. Less and less live foliage remains on shaded branches and is concentrated near the branch tips. Fewer growth substances are produced to support cambial growth at the base of the branch which is far removed from the source within the foliage. Ultimate death of the basal branch cambium occurs (Larson 1962) because growth hormones and photosynthates produced in higher branches are available for the stem cambium below them but not for the cambium of lower branches. This explains why callous tissue grows over branch scars flush with the stem but not over the ends of branch stubs projecting from the stem.

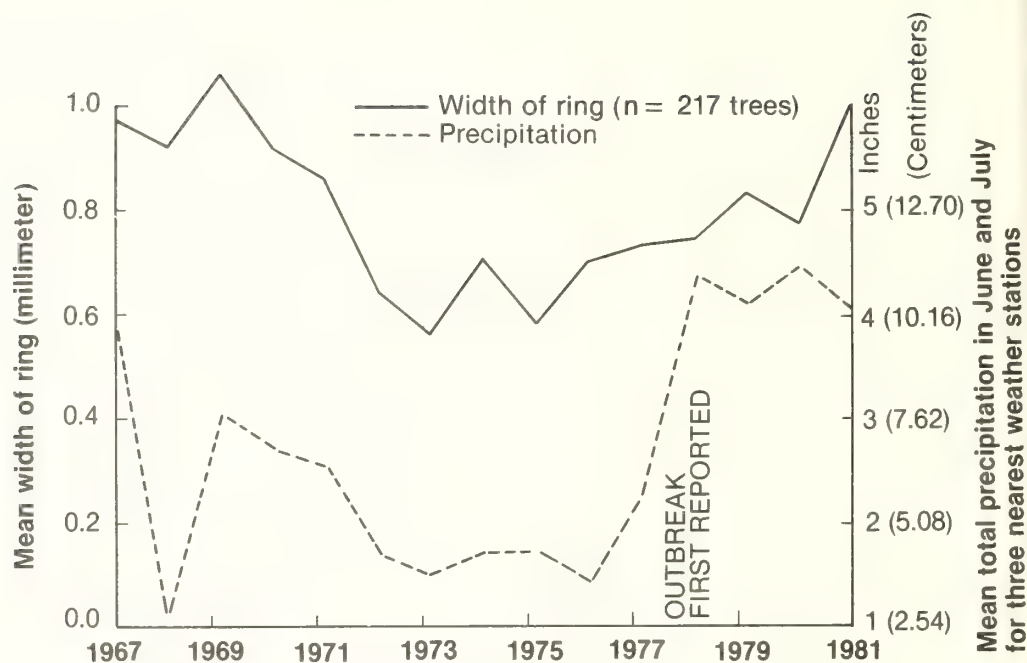


Figure 7.—Relationship of mean annual radial growth at breast height for all sample trees in figure 3 to average total precipitation during June and July at Cooper Lake, Moose Pass, and Kenai. Precipitation records for 1977 and 1978 were not available for Cooper Lake and Moose Pass, so those points represent Kenai only. Precipitation in 1980 and 1981 is for Cooper Lake and Kenai, only.

Water is also required for cambial cell division to begin after dormancy. Cambial zone cell division begins first in the partially differentiated cells at the inner margin of the cambial zone adjacent to the last-formed late wood of the previous growing season rather than in the initial cambial cells (Bannan 1962). Normally, pits are concentrated on the radial surfaces of tracheids, but horizontal ray tracheids and concentrations of pits (called growth-ring bridges) on the tangential surfaces of the last-formed late wood tracheids in the previous annual ring provide avenues for water to the cambial zone before fully functioning early wood tracheids are formed in the new ring (Zimmerman 1983).

Seasonal radial growth is not continuous. It proceeds intermittently during the growing season and is partially dependent on cambial zone hydration because water deficits in cambial regions reduce growth substantially (Kozlowski 1964). Clark (1961) showed that photosynthesis in white spruce diminished as soil moisture decreased from field capacity to the wilting point, and Fraser (1962) stated that soil moisture deficit in June and July had a greater inhibiting effect on growth of white spruce in Ontario, Canada, than at any other season because most growth occurs then. Similarly, tree growth was correlated with precipitation on the Kenai Peninsula during June and July for 1967-81 (fig. 7).

Trees in stagnated overstocked stands under continuous or pronounced repeated moisture stress suffer reduced vigor, apparently as follows: Current annual xylem and phloem rings formed in the lower bole are narrower than adjacent rings because of reduced photosynthesis in the crown which reduces translocation of growth hormones to the lower stem (Kozlowski 1964). As a result, water transport capability through the xylem is diminished, as is translocation capability of growth substances from the crown through the fewer functional sieve cells in the narrow phloem. Thus, a vicious cycle may begin because further reduced water transport may ensue, followed by reduced photosynthesis and translocation of growth substances to the lower bole and roots.

Reduced radial growth in the lower bole, which appears to create a hydraulic constriction, may be similar in effect to the constrictions that occur at branch bases in some conifers because of reduced tracheid size (Ewers and Zimmerman 1984, Zimmerman 1983); but relative conductivity of water increases toward the tops of some trees and is partially attributed to faster growth rates along the upper stem (Larcher 1983, Whitehead and Jarvis 1981). In contrast, Zimmerman (1983) states that conifer tracheids normally become longer and wider with increased stem diameter, and they also increase in size from the crown to the lower bole. These trends can be reversed, however, as radial growth slows. For example, tracheid length in white spruce shortens as ring width narrows to less than 2 mm (Bannan 1963, 1967), especially in outer rings narrower than 0.5 mm of mature trees (Bannan and Bindra 1970). Shortened tracheid length results in more cell walls and pits for water to penetrate in a vertical column of given length. This condition may further reduce the conductivity of water (Zimmerman 1983), especially in the lower boles of slowly growing trees.

Whitehead and Jarvis (1981) hypothesize that stand flow resistance of water from soil to crown within stands of comparable leaf surface area is inversely proportional to the number of stems in the stand, that fall in water potential between soil and crown depends on flow rate and flow resistance within individual trees, and that flow resistance in individual trees depends mainly on sapwood basal area and relative conductivity of sapwood tracheids. The ratio of early wood to late wood is greater in the lower bole of trees with large crowns than in trees with short, high-setting crowns (Larson 1962). Thus, water conduction is typically more efficient in the lower boles of trees with large crowns because of their proportionally wider bands of large-celled early wood and wider sapwood.

It follows that of two fully stocked stands, one densely stocked with medium diameter stems bearing small crowns and one with comparable basal area but less densely stocked with fewer large diameter stems bearing large crowns, there will be less moisture-flow resistance in individual trees of the latter stand and less chance of within-tree moisture deficits. Large diameter spruce in such stands should be resistant to spruce beetle as long as the site is not overstocked and trees continue to grow vigorously.



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Thinning is recommended for maintaining vigorous tree growth to minimize losses caused by spruce beetles (*Dendroctonus rufipennis* Kirby) and windthrow in residual stands of spruce in south-central Alaska. The anatomy of conifer stems, the variation in stem diameter growth, and the variability of tree response to wounding are discussed to explain why trees become vulnerable to attack by bark beetles. A working hypothesis, that beetle-attack patterns on the lower bole of trees have evolved to take advantage of the weak defense of a stressed tree, is presented as a rationale for maintaining vigorous tree growth.

Keywords: Thinning (-insect control, tree vigor, stand improvement, insect control, spruce, spruce beetle, south-central Alaska.

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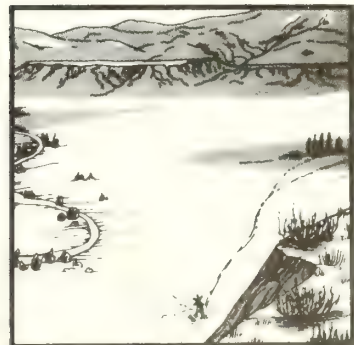
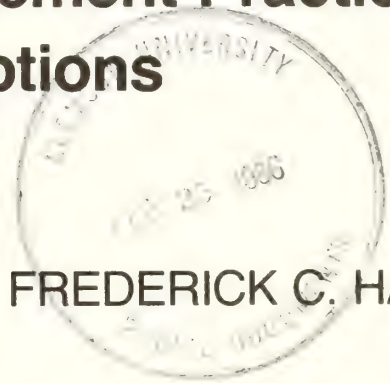
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# WILDLIFE HABITATS IN MANAGED RANGELANDS-- THE GREAT BASIN OF SOUTHEASTERN OREGON

## Management Practices and Options

FREDERICK C. HALL



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FOREST SERVICE U. S. DEPARTMENT OF AGRICULTURE

## **Abstract**

Management practices and options to provide habitat for wildlife in the Great Basin of southeastern Oregon deal with both vegetation treatment and protection, livestock management, maintenance or distribution of water developments, protection of wildlife areas through road closures or fencing, and direct manipulation of wildlife through hunting, trapping, or other means.

This chapter deals primarily with livestock management in relationship to wildlife and wildlife habitat. Included are discussions of ecological status (range condition), livestock management, multiple-use options for each species featured in previous chapters (trout, sage grouse, pronghorn, mule deer, and bighorn sheep), and diversity.

**Keywords:** Wildlife habitat management, range management, livestock, Oregon (Great Basin), Great Basin—Oregon, series (Great Basin habitats).

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This publication is part of the series **Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon**. The purpose of this series is to provide a range manager with the necessary information on wildlife and its relationship to habitat conditions in managed rangelands to make fully informed decisions.

The information in this series is specific to the Great Basin of southeastern Oregon and is generally applicable to the shrub-steppe areas of the Western United States. The principles and processes described, however, are generally applicable to all managed rangelands. The purpose of the series is to provide specific information for a particular area and in doing so to develop a process for considering the welfare of wildlife when range management decisions are made.

The series is composed of 14 separate publications designed to form a comprehensive whole. Although each part is an independent treatment of a specific subject, when combined in sequence, the individual parts are as chapters in a book.

A list of the publications in the series and their final organization is shown on the inside back cover of this publication.

**Wildlife Habitats in Managed Rangelands—The Great Basin of Southeastern Oregon** is a cooperative effort of the USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, and the United States Department of the Interior, Bureau of Land Management.





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**CAUTION:** Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

## Introduction

Management practices and options to provide habitat for wildlife in the Great Basin of southeastern Oregon deal with both vegetation treatment and protection, livestock management, maintenance or distribution of water developments, protection of wildlife areas through road closures or fencing, and direct manipulation of wildlife through hunting, trapping, or other means.

The degree of emphasis given to wildlife objectives must be clearly defined. If wildlife are of major concern to managers, livestock grazing is used to help produce a desired habitat condition. More commonly, wildlife targets are among several objectives to be produced from the same land base under the multiple-use philosophy of land management. Tradeoffs must be made between maximum production of livestock and the best possible wildlife habitat conditions.

Objectives may be stated for individual wildlife species (featured species management), for maintenance of a diversity of species (species richness management), or for a combination of the two (Maser and Thomas 1983).

This chapter deals primarily with livestock management in relation to wildlife and wildlife habitat. Included are discussions of ecological status (range condition), livestock management, multiple-use options for each species featured in previous chapters (trout, sage grouse, pronghorn, mule deer, and bighorn sheep<sup>1</sup>). The chapter concludes with a discussion of diversity.

## Ecological Status

Ecological status compares vegetation currently on a site with the vegetation that would occur if there were no fire or livestock grazing. The Society for Range Management (Range Inventory Standardization Committee 1983) de-

fined ecological status as "the present state of vegetation and soil protection of an ecological site in relation to the potential natural community." Close livestock grazing often causes current vegetation to be different from the PNC.

This concept is based on the PNC (potential natural community) that will occupy a specific site in the absence of fire or livestock grazing. When livestock graze, they forage first on the more palatable plant species. If these plants are closely eaten during active growth, their ability to grow and reproduce is seriously reduced. They eventually die, which results in a change of species in the plant community and a general decrease in forage production (fig. 1). Such changes are called range trend; a change away from the PNC is termed "downward trend," which is usually caused by close grazing; a change toward natural potential, called "upward trend," results when livestock are managed so that they graze in a way that allows adequate growth and reproduction of palatable plants (Range Inventory Standardization Committee 1983).



Figure 1.—Effects of livestock grazing on low sagebrush/wheatgrass plant community. Compare the potential natural plant community (left of fence) with the midseral stage (right of fence). Livestock overgrazed wheatgrass and cause it to decrease in density, which resulted in decreased herbage production.

<sup>1</sup>Common and scientific names are listed in the appendix.

The degree of change from the PNC is commonly identified by four condition classes: PNC, late seral, midseral, and early seral (Range Inventory Standardization Committee 1983). Potential natural community occurs when there are no significant changes caused by grazing. Late seral indicates that livestock have caused some change in the plant community and some reduction in forage production. Midseral indicates a major change in the plant community and low forage production. Early seral means that most of the palatable, native plants have been killed, forage production is very low, and adjustment of livestock grazing may not be a feasible means for attaining an upward trend (Range Inventory Standardization Committee 1983).

The Wyoming big sagebrush community is used here as an example of ecological status (fig. 2). Table 1 lists some common plant species and their crown cover that might be expected within the four condition classes. In PNC, bluebunch wheatgrass clearly dominates the herbaceous layer under a 12-percent crown canopy of sagebrush. Forage production averages about 600 lb/acre (672 kg/ha) per year, of

which wheatgrass contributes about two-thirds. Wheatgrass plants are the most palatable, and they decrease in number and vigor when they are closely grazed. Forage production also decreases. At the same time, less palatable species, such as Sandberg's bluegrass and needle and thread grass, increase, which changes the condition to late seral. With continued close grazing, even these less palatable plants are overused and begin decreasing as did wheatgrass. In the midseral condition, only vestiges of wheatgrass are present and forage production falls to one-third of the potential.



Figure 2.—Wyoming big sagebrush/wheatgrass community used as an example for ecological status.

Table 1—Ecological status classes in the Wyoming big sagebrush plant community<sup>1</sup>

Plant species	Condition classes, by crown cover			
	Potential natural community	Late seral	Midseral	Early seral
		Percent		
Wyoming big sagebrush	12	14	16	18
Bluebunch wheatgrass	10	7	4	—
Needle and thread grass	2	3	2	—
Sandberg's bluegrass	5	7	5	2
Forbs	5	6	7	5
Cheatgrass brome	1	3	7	10
<hr/>				
		lb/acre (kg/ha)		
Forage production	600 (670)	400 (450)	200 (225)	100 (110)

<sup>1</sup>Based on Range Inventory Standardization Committee (1983) criteria: Potential natural community is 75 percent or more of the ecological site potential; late seral, 50-75 percent; midseral, 25-50 percent; and early seral, 0-25 percent.



Nearly all native, palatable species may eventually be killed, which would leave the introduced annual cheatgrass brome as the primary forage producer in the early seral condition. In this plant community, the crown cover of sagebrush increases somewhat when the range trend is downward.

Sometimes the range manager's objective is to graze livestock in a manner that maintains the PNC or fosters an upward range trend toward it. At other times, existing vegetation may be manipulated to increase production of livestock forage. If sagebrush is killed in the Wyoming big sagebrush type, competition with grasses is reduced and forage production increases from an average 600 lb/acre (672 kg/ha) to about 1,100 lb/acre (1232 kg/ha). Under natural conditions, fire commonly reduces sagebrush.

In midseral and early seral conditions, cheatgrass brome is found in increasing abundance. Because it is an annual, yearly production is influenced mainly by growing conditions in the spring (Klemmedson and Smith 1964). High fluctuations in production are not conducive to sound ranch management. Therefore, crested or fairway crested wheatgrass, both perennial grasses, are commonly seeded after sagebrush is controlled. Like the native wheatgrass, they can produce 900 to 1,100 lb/acre (894 to 1232 kg/ha) of forage. Forage for wildlife, such as pronghorns, mule deer, and sage grouse, can be enhanced if adapted forbs are included.

## Characteristics of Livestock Management

Livestock management deals with grazing the right kind of animals at the right place at the right time in the proper number. What is "right" depends on land management objectives (fig. 3).

Domestic livestock management directly affects wildlife habitat in two ways—the alteration of vegetation to enhance livestock forage and the consumption of vegetation by livestock. Indirect effects on wildlife are caused by fences and water developments used to distribute livestock. These direct and indirect effects may



Figure 3.—One system of ranching in the Great Basin is a "cow-calf operation" where calves are sold in the fall after they are weaned. Distribution of cows with calves is influenced by water and by the thermal cover that may be provided by juniper trees.

cause competition for forage, create social interaction between livestock and wildlife, alter wildlife home ranges or territory through water development, introduce hazards or change wildlife use by fencing, and increase harassment from humans by roadbuilding. For a better understanding of livestock management, the following topics are discussed: behavior of livestock, livestock grazing systems, forage utilization, livestock distribution, and vegetation treatment to enhance livestock forage.

## LIVESTOCK BEHAVIOR

Cattle ranching in the Great Basin usually concentrates on one of two age classes of livestock: cows with calves or yearlings. A herd composed of cow-calf combinations is often characterized by poor livestock distribution over the range because the cow is unwilling to travel long distances with a calf at her side (fig. 3). This is particularly important when water is poorly distributed because the cow needs abundant water for milk production. Cows are often retained in the base herd 6 to 10 years. Such cows develop traditional patterns of grazing that may not provide good distribution. In general, cows scatter over the range best in the spring and fall when the weather is cooler and less energy is dissipated in movement.

Yearlings distribute themselves better across the range than cows with calves do. Because they are relatively young, they have little knowledge of the range and scatter to explore new and different environments. The youth and vigor of yearling induces them to travel farther from water and on steeper and rockier slopes than cows and calves commonly do.

Cattle are primarily grass eaters, but they do consume forbs and shrubs, such as bitterbrush and mountain-mahogany. Because they have only lower incisors and comparatively thick lips, they ordinarily graze no closer than 1 to 2 in (2.5 to 5 cm) from the ground.

Domestic sheep, when accompanied by a herder, can be distributed in almost any way the land manager desires. They can be managed in open herds with a "once over" grazing system resulting in almost imperceptible use. Or they can be tightly herded with two or three passes over the same area resulting in very close use. The method of herding and degree of utilization is at the discretion of the land manager. In general, sheep prefer forbs and, because of their small mouths and thin lips, easily crop vegetation to within 0.5 in (1.3 cm) of the ground. They can negotiate steeper and rockier topography than cattle can.

Horses are the most selective feeders among livestock, whether wild or domesticated. Grass is eaten almost exclusively, but most unevenly. Horses repeatedly graze the same grass plants and leave adjacent ones untouched. With incisors in both upper and lower jaws, they easily crop vegetation to within 0.5 in (1.3 cm) of the ground. This produces extremely uneven grazing of grasses and kills certain grass plants and leaves others of the same species untouched. Horses distribute themselves well across available rangelands because they often move long distances from water to feeding areas.

## **GRAZING SYSTEMS (CATTLE AND SHEEP)**

Livestock grazing systems are characterized by season, frequency, and intensity of use. Grazing intensity, often measured by how close to the ground (stubble height) vegetation is used, varies greatly and is hard for managers to regulate. The objective is to confine the right

animals in the right place at the right time in the proper numbers to attain the desired intensity of grazing that meets land management objectives. Pastures are usually fenced and provided with water to accomplish grazing management objectives.

In the Great Basin of eastern Oregon, season of use is generally keyed to important forage plants, such as bluebunch wheatgrass, and is related to the plant's phenological development. Early spring use starts as grasses begin growth and terminates just before the boot stage of development. Early use lasts until seed maturity. Midseason starts when grasses are in the boot stage and continues to seed maturity. Late use occurs after seed maturity but when the plants still have some green color. Fall use occurs after late use, generally during September and October after grasses have lost color and are essentially dormant. Season-long use generally runs from plant green-up (March or April) to dormancy (September to October), during which time livestock remain in the same pasture for the entire season. Winter use occurs after fall use, from November to initiation of spring growth.

These seasons of use affect plants physiologically in different ways. For example, early spring use, when livestock are removed from the pasture at about the boot stage of grass development, does little physiological damage to the grazed plants if there is enough soil moisture to allow plants to complete development through seed ripening.

On the other hand, midseason use, when grasses are grazed between the boot stage and seed ripe, has the potential of most serious physiological damage, particularly if the grass is bitten off within 1 to 2 in (2.5 to 5 cm) of the ground. In such cases, plants cannot maintain sufficient green leaves to produce adequate energy and nutrient reserves. Most of the energy and nutrients stored from the previous season are used to grow leaves and seedstalks, which cannot replace the expended energy when they are continuously grazed. Also, some nutrients must be stored in the root crowns for initiation of growth the next growing season. Close grazing not only reduces leaf surface but also prevents flowering, the physiological trigger that transfers available nutrients to root



storage. Bluebunch wheatgrass can be killed in 3 to 5 years if it is reduced to a 1- to 2-in (2.5- to 5-cm) stubble during this phenological stage. Winter use, even when plants are grazed to a 1- to 2-in stubble, seldom damages the plants physiologically. This stubble provides little protection for crown of the grass, however. Severe low temperatures with lack of snow cover can damage the plants. Grazing systems, therefore, have two objectives: to maintain or enhance plant vigor that is governed by season and closeness of use and to produce an optimum amount of livestock gain that is accomplished by good distribution of livestock and careful regulation of forage utilization.

Grazing systems vary in complexity, from season-long grazing in a single pasture to high-intensity, short duration, repeated grazing in five or more pastures (such as Savory's holistic management concept) (Walter 1984). The following discussion applies to cattle and unherded sheep, but any of the grazing systems can be applied to herded sheep on unfenced rangeland. The number of pastures, and therefore the amount of fence and the number of water developments, depends on the grazing system used.

Season-long grazing requires one pasture and enough water, generally within less than 3 mi (5.8 km), to maintain the livestock for a grazing season. Livestock are introduced in the spring and removed in the fall. Distribution is attained by placement of salt and water, or herding. In areas where western juniper occurs, thermal cover (shade) can be almost as important as water for influencing livestock distribution.

If livestock are not grazed season-long, they are most commonly moved (rotated) between two or more pastures. Rotation grazing can be divided into three kinds: deferred, rest, and high-intensity, frequent rotation.

Deferred rotation means that an entire range area is grazed every year, but some parts are deferred from grazing during some portion of the growth period of key forage species. In its simplest form, this is a two-unit system where pasture A is grazed early, during active growth in the spring and early summer and pasture B is deferred from use. Sometime about midsummer, livestock are transferred to pasture B for

late season use after forage plants have begun to mature. The next year, livestock graze early in pasture B and at midsummer are moved to pasture A.

Rest rotation requires that a certain proportion of the range area be rested completely from grazing for a whole year on a scheduled basis (fig. 4). In its simplest form, three pastures are required: pasture A is grazed during the first half of the season, livestock are moved to pasture B for the second half of the season, and pasture C is rested the entire grazing season. The next year, pasture B is grazed in the spring of the year, pasture C is grazed in the fall of the year, and pasture A is completely rested. The third year pasture C is grazed in the spring of the year, pasture A in the fall of the year, and pasture B is rested.

A third system involves high-intensity, short duration, repeated grazing developed by Savory (holistic management concept) (Walter 1984). Attention must focus on closeness of use, soil surface disturbance, and management objectives. "High intensity" does not always mean close use. Instead it means high *management* intensity in which livestock are moved when grazing on key vegetation and impacts on the soil surface reach the level specified for the pasture. In its simplest form: pasture A is grazed in the spring until use standards are met. Then livestock are moved in sequence to pastures B, C, D, and E. The time to move livestock is determined by the use level on key vegetation, degree of soil disturbance, and management objectives. Length of time in each pasture is governed by forage production and soil surface conditions. After pasture A has regrown enough to provide sufficient forage, livestock may be returned to it and may be subsequently rotated through the several pastures during the grazing season. Under this concept, most of the range area is grazed every year, often more than once. Intensity of use is adjusted according to physiological requirements of the plants and land management objectives.



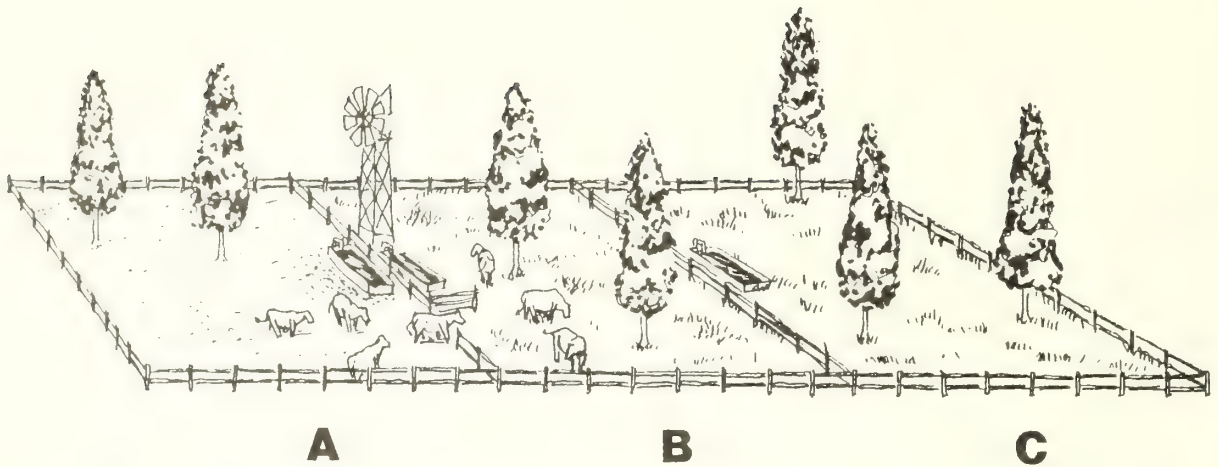


Figure 4.—One system for grazing livestock is a three-pasture, rest-rotation program. Livestock are concentrated in one pasture (A) during the first half of the grazing season, then moved to a second pasture (B). The third pasture (C) is rested for the entire season. The next year, the sequence of pastures is rotated so that a new area is rested the entire year.

- 1st year: Pasture A is grazed from June 1 to August 15; pasture B, from August 15 to October 30; pasture C is rested the entire year.  
 2d year: B, grazed June 1 to August 15; C, grazed August 15 to October 30; A, rested entire year.  
 3d year: C, grazed June 1 to August 15; A, grazed August 15 to October 30; B, rested entire year.  
 4th year: Repeat cycle, starting with A.

### CLOSENESS OF FORAGE USE

Deferred rotation, rest rotation, and high-intensity, short duration grazing systems have one thing in common—close use of vegetation in pastures being grazed. All systems concentrate livestock in a relatively small tract where preferred grazing areas are quickly cropped to a stubble of 1 to 2 in (2.5 to 5 cm). The animals must then graze farther from water in less preferred areas. Vegetation near water is expected to be closely grazed. One objective of these systems is forced distribution of livestock so more of the total area can be grazed. Another objective is deferred use of plants on some portion of the area to restore their vigor.

This concentration of livestock and their close use of vegetation have impacts on wildlife; these impacts will be discussed later for each of the species featured in previous chapters. Grazing by livestock can be advantageous or disadvantageous to wildlife depending on species and circumstances. For example,

a 1- to 2-in (2.5- to 5-cm) stubble is roughly equivalent to bare ground for wildlife that nest and feed on the ground. On the other hand, seasonal grazing by livestock removes old grass called "rough" and exposes regrowth of lush green grasses often heavily used by mule deer. A 6-in (15-cm) stubble may be as adequate as ungrazed bunchgrass for ground-dwelling wildlife.

Close use of vegetation by livestock does more than influence wildlife and wildlife habitat. It can affect plant species composition and density of the herbaceous layer. Repeated, close use to 1- to 2-in (2.5- to 5-cm) stubble during the growing season results in a decrease of bunchgrasses. This downward trend results in a midseral or an early seral condition characterized by dominance of the annual cheatgrass brome. On poor soils, the result may be essentially bare ground. But the midseral or even the early seral condition is not detrimental to all wildlife. For example, figure 5 (Maser et al. 1984) suggests that a greater number of

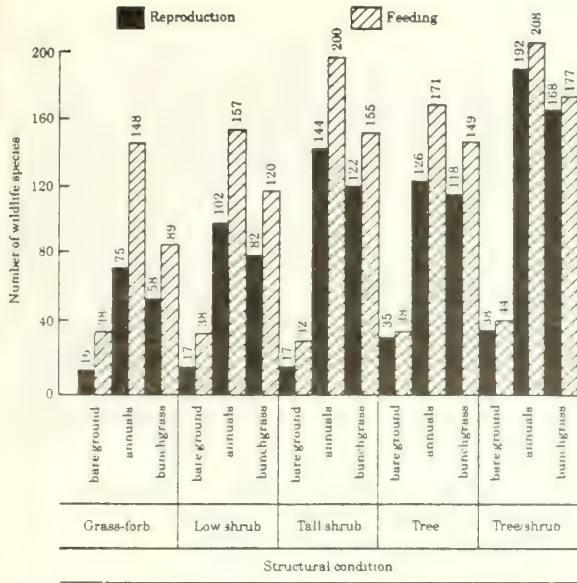


Figure 5.—Number of wildlife species oriented to desert-steppe structural conditions and the potential effect of intensive management (reproduced from Maser et al. 1984).

wildlife species both reproduce and feed when annuals are dominant in the grass-forb, low shrub, tall shrub, tree, and tree/shrub structural conditions.

## FENCES AND WATER

Livestock distribution is achieved primarily by means of fencing, water development, salt location, and maintenance of thermal cover where juniper or tall shrubs occur. Cattle will scatter over ranges with gentle topography when water is no farther than 2 mi (3.2 km) apart. In the Great Basin, natural water sources are seldom found this close together; therefore, additional sources of water are often developed. If wildlife enhancement is a management objective, these water sources should remain available throughout the season. This may be expensive if water is hauled or supplied by electric pump (fig. 6).



Figure 6.—Many water developments in the Great Basin are not natural. Well-placed water is the best means for obtaining good livestock distribution; however, these manmade water developments are of little benefit for wildlife if water is not maintained while wildlife are in the area. In this example, an electric pump would be needed to supply water. (Photograph courtesy of Chris Maser.)

Fencing is the primary means by which livestock are contained within a specified area. Fences have significant impacts on wildlife movement, particularly pronghorns and bighorn sheep. A smooth wire at least 16 in (41 cm) above the ground and a top wire no higher than 36 in (92 cm) have the least impact on movement of pronghorns; for bighorn sheep, a smooth wire 20 in (51 cm) above the ground and a top wire no higher than 39 in (100 cm) have the least impact. A general recommendation is a smooth bottom wire 20 in (51 cm) above the ground, a top barbed wire no higher than 36 in (92 cm), and a third barbed wire between the other two wires. If steel fenceposts are used, their tops should be painted white to enhance visibility. Making the fence obvious is important in preventing collisions by wild ungulates and birds, such as sage grouse.



In many areas, soils are too stony and shallow to allow steel fenceposts to be easily driven into the ground. Fences in such situations are commonly constructed from rockjacks or rockcairns (fig. 7). Such fences can provide habitat attributes for some wildlife species. For example, rockjacks can provide cover and dens for small animals, particularly with a 4- to 6-in (10- to 15-cm) gap between the ground and the bottom of the rockjack. Rocks greater than 12 in (31 cm) in diameter provide large enough crevasses for several species of wildlife (Maser et al. 1979).

## VEGETATION TREATMENT

When land is managed primarily for livestock production, the principal reason for manipulating vegetation is to increase forage for livestock. In the Great Basin, this often entails killing or removing shrubs, trees, or both to reduce competition with grass. Where sites are in the late seral or the PNC condition, control of woody species allows native grasses and forbs more nutrients, moisture, and sunlight. With these nutrients they will be more productive and will provide additional forage for livestock.

When such sites are in the midseral or the early seral condition, not enough bunchgrasses remain to provide adequate forage, so the area is often seeded to crested or fairway crested wheatgrass. On a Wyoming big sagebrush site dominated by sagebrush, for example, the midseral condition may produce only 200 lb/acre (224 kg/ha) of forage in the form of cheatgrass brome and Sandberg's bluegrass. With shrub control and successful seeding of crested wheatgrass, forage production can be increased to 900 to 1,100 lb/acre (1010 to 1235 kg/ha).

The method of vegetation manipulation influences structure and dominance of plants after treatment. For example, burning, whether natural or prescribed, not only kills woody plants but also eliminates their structure from the stand. It may enhance habitat for a number of wildlife species. Mule deer and pronghorns often select recently burned areas for feeding (Leckenby et al. 1982, Kindschy et al. 1982). On the other hand, chemical control of shrubs has two significantly different after



Figure 7.—Fences are the second most important means for controlling livestock. On soils too shallow to support steel fenceposts, rockjacks are used for stability.

effects. First, the dead shrubs remain, and they often retain the shrub structure that does not enhance the areas for such species as the horned lark and bighorn sheep. Second, chemicals that kill the shrubs, such as 2,4-D, also kill forbs. Forbs are part of the staple diet for sage grouse (Call and Maser 1985) and pronghorns (Kindschy et al. 1982). Mechanical treatment of woody vegetation has intermediate effects on wildlife. For example, chaining changes the structure from tree/shrub or shrub to grassland but leaves residue on the ground that creates microhabitat for small animals (Maser et al. 1979).

The consideration of edges by managers when they are planning treatments to vegetation can have important ramifications for wildlife (Thomas et al. 1979). In general, some treatment of large, homogeneous tracts is advantageous to wildlife, such as mule deer (Leckenby et al. 1982) and pronghorns (Kindschy et al. 1982) (fig. 8). On the other hand, heterogeneous vegetative complexes composed of natural grassland, low shrub, tall shrub, and tree/shrub communities may already be close to optimum in terms of habitat diversity and wildlife. Manipulation of vegetation could cause simplification of vegetative structure and thus reduce diversity (fig. 9).





Figure 8.—In some plant communities, such as Wyoming big sagebrush, herbage production for livestock can be greatly increased by seeding crested wheatgrass after sagebrush is controlled. Interspersion of revegetated tracts in a homogeneous tract of sagebrush can enhance wildlife habitat by creating edges and introducing different stand structure and thus increasing wildlife diversity.



Figure 9.—An area with good natural diversity of plant communities: quaking aspen, meadow, Wyoming big sagebrush, and low sagebrush ridges. Revegetation on the hills adjacent to the aspen and meadow might increase herbage production but might not enhance vegetation diversity to the advantage of wildlife.

It is not possible to deal with all wildlife species of the Great Basin here; however, the wildlife species featured in other chapters in this series are discussed in relation to livestock management. This discussion shows how wildlife can be considered in relation to management of livestock grazing.

## Featured Species and Grazing

Habitat characteristics have been summarized from the chapters in this series that deal with the following species: native trout (Bowers et al. 1979), sage grouse (Call and Maser 1985), pronghorns (Kindschy et al. 1982), mule deer (Leckenby et al. 1982), and bighorn sheep (Van Dyke et al. 1983).

### NATIVE TROUT

Livestock impacts on native trout occur primarily in riparian areas. Optimum habitat for native trout has the following characteristics: water temperatures less than 70 °F (21 °C), stable streambanks, minimum sedimentation, and adequate instream or streambank cover. Streamside vegetation is particularly important as it provides shade that reduces water temperature, produces leaves that fall into the stream for primary and secondary reducers, both of which are food for trout, and provides habitat for other insects that can be eaten by trout. In addition, abundant streambank vegetation reduces erosion and thus minimizes siltation over spawning gravel. Instream cover, such as boulders, is also important, but overhanging vegetation along the streambanks more than 2 ft (0.6 m) above the water can effectively replace instream cover (fig. 10).



Figure 10.—Stream edge in the riparian area healing from past heavy use by livestock. In many cases, light to moderate use, such as leaving a 4-in (10-cm) stubble, is compatible with enhancement of the riparian vegetation. (Photograph courtesy of Oregon Department of Fish and Wildlife.)

Livestock use in riparian areas can affect trout habitat in several ways. As cattle travel to and from water, they can break overhanging streambanks that partially shade the stream. Close cropping of forbs and grasses by cattle reduces vegetation along the streambank and often prevents or eliminates woody vegetation that can provide shade to the stream system. Some studies in the Great Basin area and elsewhere have demonstrated a twofold to threefold increase in trout biomass with livestock use controlled enough to permit banks to build an overhang and woody vegetation to colonize and grow along the streambank (Bowers et al. 1979).

Intensity of livestock use is apparently the key to maintaining or enhancing native trout habitat. When vegetation is grazed to a 1- to 2-in (2.5- to 5-cm) stubble for extended periods, establishment and growth of woody vegetation are inhibited and overhanging banks do not develop. Such stubble heights are common in deferred and rest rotation grazing systems because livestock are grazed in sufficient numbers to force use away from the riparian areas onto less palatable dryland forage. Light to moderate livestock use, leaving a 4- to 6-in (10- to 15-cm) stubble, appears compatible with protection of the riparian area and native trout habitat.

## SAGE GROUSE

Sage grouse depend almost entirely on areas dominated by sagebrush for habitat. They prefer level to low rolling topography with slopes generally less than 30 percent. Some sage grouse migrate from lower to higher elevations after forbs develop though they remain mainly in sagebrush-dominated areas. Their movements are strongly influenced by the availability of free water; they therefore have strong affinities for riparian areas. Breeding occurs in the spring on open areas called leks (fig. 11). These areas are characterized by bare or relatively bare ground and range in size from 10 to 100 acres (4 to 40 ha). Leks are usually adjacent to nesting and brood-rearing habitat.



Figure 11.—Sage grouse strutting on a lek. The lek characteristically has little or no sagebrush and is in early seral to midseral community. It is usually adjacent to nesting areas where sagebrush is essential. (Photograph courtesy of Oregon Department of Fish and Wildlife.)

Optimum nesting habitat is characterized by 20 to 40 percent crown cover of sagebrush ranging from 7 to 30 in (18 to 77 cm) tall. A dense understory of herbaceous vegetation is important; a late seral condition or PNC is near optimum habitat. Close early grazing by livestock is a disadvantage to sage grouse because it reduces cover and availability of forbs important as food during the nesting and brood-rearing seasons.

Brood rearing occurs in sagebrush but requires only 8 to 14 percent crown cover of shrubs shorter than those preferred for nesting habitat. Low sagebrush types are commonly used during brood rearing; an interspersed of openings is considered advantageous. Sage grouse move away from snow-covered areas to lower elevations to spend the winter, during which time they feed almost exclusively on sagebrush leaves. Sage grouse seem to prefer low sagebrush, but when this species is covered with snow they will feed on taller sagebrush species. Sagebrush canopy cover exceeding 15 percent characterizes the best sage grouse winter ranges.

Local knowledge of sage grouse behavior is essential in developing land management plans. Grouse have strong tendencies to use the same lek year after year and the same nesting and brood-rearing areas. Almost any vegeta-



tion treatment within 2 mi (3.2 km) of a lek can have detrimental effects on sage grouse welfare. Therefore, the land manager should determine the location of all leks that are to be maintained as part of the management plan.

This does not, however, preclude some manipulation of vegetation within occupied sage grouse ranges. For example, sage grouse will use areas with sagebrush below the preferred 20 to 40 percent crown cover. Some treatment of sagebrush, such as reducing cover from 40 to 20 percent may not seriously degrade habitat. Indeed, it might provide for more herbaceous food plants. Sagebrush control in areas with less than 20 percent shrub cover is generally considered detrimental. Treatment of sagebrush might be confined to a few of the most productive sites for livestock forage and adequate stands be left between treated areas.

New leks might be developed by removing sagebrush, provided they are adjacent to good nesting and brood-rearing habitat. Sagebrush can be removed from 10- to 100-acre (4- to 40-ha) tracts on sites in midseral and early seral conditions that would provide minimum ground vegetation. These leks can be made additionally attractive if free water is provided nearby.

Intensity of livestock use can affect the success of sage grouse nesting and brood rearing. Nesting requires both sagebrush cover and herbaceous plants. Therefore, grazing to a 1- to 2-in (2.5- to 5-cm) stubble during these activities is detrimental. Such close grazing will result in significant use of spring forbs by livestock; these forbs are a key element in the grouse diet. If management of sage grouse is an objective, the land manager might consider grazing livestock to leave a 4- to 6-in (10- to 15-cm) stubble. This will provide some cover and also provide sufficient forbs for spring use by nesting and brood-rearing grouse.

When vegetation in sage grouse habitat is treated, special concern should be directed toward use of chemicals, such as 2,4-D. Chemicals kill sagebrush and thus eliminate sagebrush forage for the grouse and reduce hiding cover. In addition and perhaps equally important, these same chemicals may kill the forbs that are essential in the spring and early summer diet of sage grouse.

## PRONGHORNS

Pronghorns prefer level to gently rolling topography as habitat. Large bodies of water, escarpments, mountains, canyons, and tall shrub or forest areas are barriers to their movements. They require water with a pH less than 9.25 and less than 4,500 p/m of solids. Optimum habitat is about 50 percent crown cover of plants, a significant portion in herbaceous vegetation (fig. 12). They avoid sagebrush areas where the shrubs exceed 20 in (51 cm) in height. Because they are primarily forb eaters, the midseral condition seems optimum. Pronghorns effectively use crested wheatgrass seedlings if forbs have been seeded.



Figure 12.—Pronghorns prefer areas with little or no shrub cover and a high proportion of forbs in the herbaceous vegetation. Optimum ecological status is midseral to late seral. Grass seeding can enhance pronghorn habitat if forbs are seeded in the mixture. (Photograph courtesy of Oregon Department of Fish and Wildlife.)

A high diversity in plant species composition seems attractive to pronghorns. Extensive tracts of homogeneous shrubland, such as 3,000+ acres (1215+ ha) of Wyoming big sagebrush, are not optimum pronghorn habitat. Habitat can be enhanced by manipulation of vegetation. For example, controlling sagebrush or western juniper on areas less than 1,000 acres (405 ha) and generally no more than one-third the home range of pronghorns can be beneficial. In treatment of vegetation, the manager should remember that chemicals may kill desired forbs. Fire can be an effective means of



manipulating vegetation to benefit pronghorns. Fire can be prescribed to result in less than 100 percent kill of sagebrush, and it stimulates forbs and enhances palatability of forage. Pronghorns have been observed seeking out burned areas for feeding (Kindschy et al. 1982).

Fencing can be detrimental to pronghorns. Because pronghorns do not commonly jump, the lower wire of a fence should be high enough to permit them to crawl under it. A smooth wire 16 in (41 cm) above the ground is acceptable. The fence should have no stays, and white-topped fenceposts will make the fence more visible to pronghorns. Water developments to enhance livestock distribution can be of significant advantage to pronghorns if they are available when pronghorns occupy the area.

Moderate cattle grazing seems complementary to pronghorns because cows, preferring grasses, leave the forbs for the pronghorns (Kindschy et al. 1982). Cattle grazing must be controlled if close use of forbs is to be avoided. Some direct competition occurs between domestic sheep and pronghorns because both species feed primarily on forbs. If pronghorn welfare is a primary concern, sheep should not be grazed. If sheep are to be grazed, the closeness of use should be limited to assure that appropriate amounts of forbs remain for the pronghorns. Although close livestock use seems to be detrimental (that is, a 1- to 2-in (2.5- to 5-cm) stubble), moderate livestock use that leaves a 4- to 6-in (10- to 15-cm) stubble, may be complementary to both livestock and pronghorn welfare. Sufficient winter forage should remain for the pronghorns after livestock grazing. Some moderate use may make grasses the pronghorns eat more palatable by removing old rough grass.

## MULE DEER

Mule deer use traditional home ranges whether they are migratory or are year-round residents. For this reason, management relating to mule deer should consider subpopulation areas of about 11,500 acres (4656 ha). Two kinds of social groups are common: does with fawns, and males. Five habitat attributes are

important: (1) thermal cover, (2) hiding cover, (3) forage areas (4) fawning habitat, and (5) fawn-rearing habitat. Thermal cover is provided by woody vegetation over 5 ft (1.5 m) tall, with crown cover exceeding 50 percent in tracts at least 2 to 5 acres (0.8 to 2.0 ha). Hiding cover is defined as vegetation greater than 24 in (61 cm) tall that can hide 90 percent of a bedded deer at 150 ft (46 m) or less (fig. 13). Tracts should be at least 600 to 1,200 ft (183 to 366 m) in diameter, which equals 6 to 25 acres (2.5 to 10 ha). Forage areas are defined as tracts where the structure of the vegetation does not meet thermal or hiding cover criteria but does produce forage. Because mule deer have affinities for edges, forage areas should be less than 1,200 ft (366 m) across. Deer and cattle compete for forage; however, moderate cattle use, which removes rough grass, can enhance these areas for deer.



Figure 13.—Mule deer in hiding cover—shrubs tall and dense enough to hide 90 percent of a bedded deer at 150 ft (45.7 m). They have affinity for edges in landscapes with a variety of plant communities and structural conditions. (Photograph courtesy of Oregon Department of Fish and Wildlife.)

Fawning habitat is characterized by shrubs greater than 28 in (72 cm) tall and with more than 40 percent crown cover, is within 160 ft (50 m) of tree cover, has succulent forage, is 5 to 25 acres (2 to 10 ha) in size, and is close to water—within 2,000 ft (610 m). This description suggests that riparian areas are optimum habitat. Fawn-rearing habitat is similar to fawning habitat; however, it is desirable to have larger tracts of land with more diverse

plant communities. The optimum diversity of mule deer habitat is 55 percent in forage area, 20 percent in hiding cover, 10 percent in thermal cover, 10 percent in fawn-rearing habitat, and 5 percent in fawning habitat. Thermal cover is thought to be a critical component. If adjustments in cover are desired, thermal cover should be increased at the expense of other cover.

In treatment of vegetation to enhance mule deer habitat, current vegetative conditions must be considered. Variable topography and a variety of plant communities creating a mosaic of edges, forage areas, and cover enhance mule deer habitat. Extensive tracts of homogeneous vegetation, such as Wyoming big sagebrush, can be significantly improved for mule deer habitat by vegetation treatment; as much as 55 percent of an area can be treated to remove or reduce sagebrush to create forage areas. The key is to select the sites best suited for forage production. Then other characteristics of habitat should be considered such as maintaining widths less than 1,200 ft (366 m) across treated areas, maximizing edges, and providing for sufficient thermal cover. Water should be kept available to mule deer when they are on the area.

Intensity of livestock use can be adjusted to enhance production of forage for mule deer. Moderate use by cattle will remove rough grass and afford deer the opportunity to forage on regrowth or spring growth of grasses protruding above the rough. Livestock grazing should be regulated to insure only light use of forbs and browse. Close livestock use, which causes a downward range trend, can be detrimental to mule deer range.

## BIGHORN SHEEP

Bighorn sheep are very traditional in their occupation of specific ranges, are slow to pioneer new habitats, and are extremely sensitive to disturbance. They prefer remote, rugged, steep terrain with open plant communities that are low in structure. Keen vision is their primary mechanism for detecting danger. They shun forest stands and areas with shrubs more than 2 ft (0.6 m) tall. Key habitat components

are open forage areas, escape terrain, water, thermal protection, and traditional lambing and rutting areas (fig. 14).



Figure 14.—Bighorn sheep in a near ideal setting of forage area, escape cover, and terrain that significantly limits easy travel by other large animals. They are socially sensitive to domestic livestock and often leave areas grazed by cattle. (Photograph courtesy of Walter A. Van Dyke.)

Presence of escape terrain regulates use of other areas. Such escape terrain is composed of cliffs, rimrock or outcroppings, bluffs, and topographic features most other animals have difficulty negotiating. Thermal protection is often provided by topography and elevation. Bighorn sheep also obtain thermal regulation by bedding in windy or wind-protected areas depending on the circumstances. Forage areas are relatively open with low vegetation, no farther than 0.5 mi (0.8 km) from escape terrain and within 1 mi (1.6 km) of water. Shrubs are mostly less than 2 ft (0.6 m) tall with less than 25 percent crown cover. Lambing areas are traditional; they occur in rugged, precipitous, remote terrain with adequate forage and water. In general, they exceed 5 acres (2 ha) in size. Intrusion by people and competing animals is detrimental. Fresh water with a reasonably low pH is important. Water in summer is of particular value.



Because bighorn sheep are primarily grass eaters, they compete directly with cattle for forage. They will sometimes leave areas grazed by livestock because of their sensitivity to this competition. For enhanced conditions for bighorn sheep, livestock should not be grazed with bighorn sheep; if they are grazed, use should be adjusted to leave sufficient forage for sheep.

Fences are important in controlling livestock, but they may hinder movement of bighorn sheep. Recommended fence construction is a smooth wire 20 in (51 cm) off the ground with a top barbed wire no higher than 39 in (100 cm) above the ground.

Transmittal of diseases between bighorn sheep, cattle, and particularly domestic sheep, sometimes is a problem. Waterholes and salt grounds should not be used by domestic livestock when bighorn sheep are in the area.

Human intrusion into bighorn sheep territory is most detrimental. The sheep have abandoned good habitat because of their low tolerance for humans. Therefore, management should provide for control of people.

These constraints on bighorn sheep habitat seem to imply that no management activities should be carried out on ranges occupied by bighorn sheep. This is not necessarily true. For example, forage areas adjacent to escape terrain and available water may be improved by shrub control. Grasses and forbs can be seeded on ranges depleted of perennial grasses. Water sources can be developed to enhance bighorn sheep range. In general, these improvements should be fenced to exclude livestock if bighorn sheep habitat is to be enhanced to its fullest. If cattle are to graze in bighorn sheep range, they must be carefully controlled as to season and intensity of use to avoid social interaction and forage competition with bighorn sheep.

## Management for Species Richness

So far, livestock management has been discussed as it affects several featured species. An alternative or additional wildlife objective is species richness management in which habitat is manipulated to insure that all native species remain in viable numbers in the area under management (Maser and Thomas 1983).

Diversity was thoroughly discussed in the chapter of this series on edges (Thomas et al. 1979), which dealt with interspersions, inherent and induced edges, species richness, size of habitat blocks, and contrast in structure of plant communities. Tract management for species richness is based on habitat blocks averaging about 200 acres (81 ha) in size.

The land manager commonly must strike a balance between meeting species richness goals and optimizing habitat for one or several featured species (fig. 15). For example, optimum mule deer habitat has 55 percent of the land in forage areas that is in the grass-forb structural condition (Leckenby et al. 1982). For optimum habitat for pronghorns only 33 percent of the area need be in a grass-forb structural condition (Kindschy et al. 1982), whereas for sage grouse habitat only 2 percent of the land area need be in a grass-forb structural condition (Call and Maser 1985). Clearly, the land manager cannot manipulate vegetation so as to maximize habitat conditions for mule deer, pronghorns, and sage grouse on the same tract of land. Similarly, the manager cannot maximize species richness and the habitat conditions for a featured species on the same tract at the same time.

The land manager must deal with the interaction of livestock and wildlife. Livestock, with their attendant use of forage, compete directly with some species of wildlife for forage; they create adverse effects for some wildlife through social interactions or produce a complementary situation for some wildlife species, depending on the intensity of livestock grazing and the season of use. Properly done, livestock grazing can enhance mule deer habitat, whereas livestock presence can be an intolerable intrusion on bighorn sheep ranges.



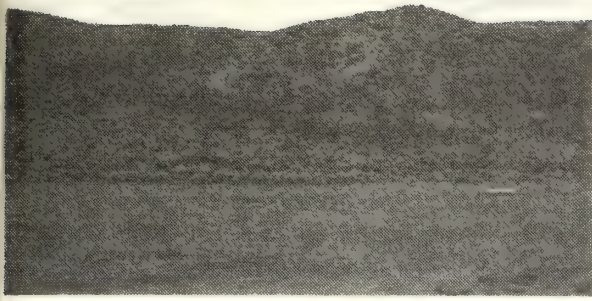


Figure 15.—Diversity in plant communities and stand structure provides for a variety of wildlife habitats and therefore enhances wildlife species richness. Species richness may be enhanced by vegetation treatment in areas with large expanses of homogeneous vegetation. In this case, the best grass growing area has been seeded to crested wheatgrass to create habitat for horned larks, a forage area for pronghorns, and edges for mule deer. (Photograph courtesy of Chris Maser.)

Practices for the simultaneous management of livestock and wildlife in the Great Basin constitute a complex series of tradeoffs involving biology, economics, legal requirements, and social pressures. At least for the present, livestock grazing is the dominant use of the lands in question. The task for the manager, then, is to determine how best to manage livestock and manipulate vegetation in a cost-effective manner for enhanced livestock production, and at the same time provide a minimum detrimental impact on wildlife or, if possible, enhance wildlife habitat. Even if livestock grazing were excluded from public lands in the Great Basin, the resulting circumstances would not provide optimum habitat conditions for featured species or ideal conditions for species richness. For example, very large tracts of climax sagebrush is not optimum habitat for most wildlife species in the Great Basin of southeastern Oregon (Maser et al. 1984). The land manager has a myriad of opportunities and constraints to consider when formulating management objectives and alternatives. In general, no matter what the manager does or does not do, the habitat of some species of wildlife will be enhanced and that of others diminished. It is the clear intent of the law under which public land managers operate (see Maser and Thomas 1983) that these effects be considered and

evaluated when management decisions are made. The chapters in this series provide the means to deal with wildlife in the managed rangelands of southeast Oregon.

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## Appendix

### COMMON AND SCIENTIFIC NAMES

Common name

Scientific name

#### PLANTS

Bitterbrush	<i>Purshia tridentata</i>
Bluebunch wheatgrass	<i>Agropyron spicatum</i>
Cheatgrass brome	<i>Bromus tectorum</i>
Crested wheatgrass	<i>Agropyron desertorum</i>
Fairway crested wheatgrass	<i>Agropyron cristatum</i>
Low sagebrush	<i>Artemisia arbuscula arbuscula</i>
Mountain-mahogany	<i>Cercocarpus ledifolius</i>
Needle and thread grass	<i>Stipa comata</i>
Quaking aspen	<i>Populus tremuloides</i>
Sagebrush	<i>Artemisia spp.</i>
Sandberg's bluegrass	<i>Poa sandbergii</i>
Western juniper	<i>Juniperus occidentalis</i>
Wheatgrass	<i>Agropyron spp.</i>
Wyoming big sagebrush	<i>Artemisia tridentata wyomingensis</i>

#### ANIMALS

Bighorn sheep	<i>Ovis canadensis</i>
Cow	<i>Bos taurus</i>
Domestic sheep	<i>Ovis aries</i>
Horned lark	<i>Eremophila alpestris</i>
Horse	<i>Equus caballus</i>
Mule deer	<i>Odocoileus hemionus</i>
Native trout	<i>Salmo spp.</i>
Pronghorn	<i>Antilocapra americana</i>
Sage grouse	<i>Centrocercus urophasianus</i>





**WILDLIFE HABITATS IN MANAGED RANGELANDS—THE  
GREAT BASIN OF SOUTHEASTERN OREGON**

**Technical Editors**

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Native Trout	Gen. Tech. Rep. PNW-84
Sage Grouse	Gen. Tech. Rep. PNW-187
Pronghorns	Gen. Tech. Rep. PNW-145
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Bighorn Sheep	Gen. Tech. Rep. PNW-159
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# Spatial and Regional Analysis Methods in Forestry Economics: An Annotated Bibliography



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# **Spatial and Regional Analysis Methods in Forestry Economics: An Annotated Bibliography**

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This bibliography provides extensive coverage of a relatively new field of study. Entries relate to models, techniques, and information regarding spatial and regional analysis printed before 1981.

Forest economics has always included spatial and regional analysis. Nevertheless, the central analytical core of forestry economics has been almost exclusively based on neoclassical microeconomics, which assumes that the spatial dimension of resource management decisions is relatively unimportant. In recent years, however, a great deal of research has been completed that applies regional economic concepts and methods to the analysis of natural resources, including forest resources. This annotated bibliography attempts to provide extensive coverage of publications in this relatively new field of study.

The main criterion for selecting publications for inclusion in this bibliography was that they should relate to models, techniques, and information of spatial and regional analysis that have been or could be applied to some economic factor, aspect, or problem involving forest resources.

Entries are listed alphabetically by author(s). Major sources consulted in developing this annotated bibliography were library collections and published bibliographies. Most citations are accompanied by an annotation. Materials from which annotations were adapted are from periodicals, articles, books, and other annotated bibliographies.

Although this bibliography is not an exhaustive treatment of the subject matter, we include what we believe are important citations for information printed before 1981. We believe these citations will provide a good source of information to individuals wishing to conduct in-depth study of important forestry economics research.

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1. Adams, Darius M. Forest products prices and National Forest timber supply in the Douglas-fir region. *Forest Science*. 20(3): 243-259; 1974.

This paper presents a quarterly econometric model of forest products markets of the Douglas-fir region. Through simulations, regional price and output behavior were examined under alternative National Forest timber supply policies.

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An application of linear programming to the planning of forest road construction is illustrated. Movement of earth for cuts and fills is formulated as an allocation problem, and an optimal solution is obtained by linear programming.

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New processes can help forest management provide selected optimal forest benefits in perpetuity. A system dynamics technique, DYNAST-OB, is a mechanical method for quantifying and interrelating different kinds of forest benefits. This model has the capacity to integrate management strategy and tactics for a complex area divided into types or categories.

25. Boyd, Kenneth G. Water transport of wood: B.C. coast. Pulp and Paper Canada. 80(11): 28-34; 1979.

Mills on the British Columbia coast depend on water to transport their wood supply. Larger carriers are more efficient, but the high capital costs for such equipment deter investments.

26. Bradley, Dennis. Improve forest inventory with access data--measure transport distance and cost to market. Res. Pap. NC-82. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1972. 21 p.

This paper describes a fairly simple model relating transport distance to: (1) length of the road network per unit of land area, (2) the distribution of the road network, (3) the terrain, and (4) the location of specific delivery points.

27. Bradley, Dennis P. Solving wood chip transport problems with computer simulation. Res. Pap. NC-138. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1978. 8 p.

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29. Brazzel, John M.; Hicks, W. Whitney. Export and regional economic growth: an evaluation of the economic base and staple models. Land Economics. 44: 503-509; 1968.

This paper contends that the two models--economic base and staple--represent similar explanations of regional growth and that differences between the models are complementary.

. Brodie, D.; McManon, R.; Gavelis, W. Oregon's forest resources: their contribution in the State's economy. Resour. Bull. 23. Corvallis, OR: Oregon State University, School of Forestry; 1978. 78 p.

Authors review forest products industry employment in Oregon (SIC codes 24, 25, 26), shifts within the industry, value of products, relation of the industry to all manufacturing, and various other items related to the importance of the industry in Oregon.

. Bromley, Daniel W. An alternative to input-output models: a methodological hypothesis. Land Economics. 48(2): 125-133; 1972.

A considerable amount of information about the economic structure of rural economies can be discerned without the implementation of a complete input-output study. Two indexes that form the basis for understanding an economy are defined, the index of internal purchases and the index of external sales.

. Bromley, Daniel W.; Blanch, G.E.; Stoevener, H.H. Effects of selected changes in Federal land use on a rural economy. Bull. 604. Corvallis, OR: Oregon State University, Agricultural Experiment Station; 1968. 27 p.

Authors used a primary data base input-output model to examine the relative importance of logging on Federal range land and lumber production to the Grant County, Oregon, economy. They compared a 20-percent reduction in use of Federal ranges with a 10-percent increase in the output of the lumber sector. The decrease in use would reduce gross business income in the county \$623,739, whereas the increase in output would increase income by \$1,784,243.

. Brookshire, David S. A macroeconomic analysis of regional environmental modeling and planning. Journal of Environment and Management. 5(3): 268-282; 1978.

Two models are presented: an expanded inter-regional model that incorporates regional disamenities into the multiplier structure and a regional migration model for estimating disamenities. The results suggest that failure to include corrections for disamenities in regional multipliers will lead to greater regional inequality in welfare.

34. Brown, N.; McMillan, J.A. Recreation program development impacts: a dynamic regional analysis. American Journal of Agricultural Economics. 54(4): 750-754; 1977.

The purpose of this article is to compare impacts of a recreation program relative to agricultural development programs using a dynamic regional economic model. The article is organized into three sections: (1) the inclusion of recreation in a regional model, (2) an assessment of recreation versus agricultural development programs, and (3) development policy implications.

35. Browne, L.E.; Mieszkowski, P.; Syron, R.F. Regional investment patterns. New England Economic Review. July/August: 5-23; 1980.

Simple representations for differences in regional investment between 1959 and 1976 were shown to account for only about one-third of the variation. Wage differentials and relative energy costs were important, but intangibles and historic accidents were also significant factors behind investment decisions.

36. Bryne, J.J.; Nelson, R.J.; Googins, P.H. Logging road handbook: the effect of road design on hauling costs. Agric. Handb. 183. Washington, DC: U.S. Department of Agriculture; 1960. 65 p.

Analyzes hauling costs, the use of diesel and gas-driven trucks, size of hauling unit, and type of road.

37. Buckman, Robert E.; Fight, Roger D. Multi-resource inventories...resolving conflicts. Inventory design and analysis. In: Proceedings of a workshop; SAF Inventory Working Group 1974; Ft. Collins, CO. Colorado State University; 1974: 181-185.

An analysis of the role of multiresource inventories in resolving conflicts is presented. The authors conclude that conflict in resource decisionmaking does not result primarily from a lack of inventory data. Inventory data, however, are an essential link in resource decisionmaking and can play an important role in focusing the conflict on the real issues.



38. Bureau of Governmental Research and Service. The significance of the O and C forest resource in western Oregon. Eugene, OR: University of Oregon; 1968. 169 p.

Describes historical highlights of the Oregon and California railroad land grants and the importance of O and C timber harvests in the Oregon economy. Income derived from the O and C forest resource and expenditure patterns of dependent counties are given. A case study of Josephine County, Oregon, is described to identify and measure the impacts of the O and C forest resource in a comprehensive and detailed manner.

39. Business-Economics Advisory and Research, Inc. The role of forest land in Washington economy. Seattle, WA: Washington Forest Protection Association; 1970. 55 p.

Describes the contribution of forest lands and forest-based industries to the economic well-being of the State of Washington.

40. Carpenter, Eugene M. Transportation facilities for developing wood-using industries in north-eastern Minnesota. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest and Range Experiment Station; 1964. 34 p.

Describes the transportation facilities and services available in northeastern Minnesota and compares shipping rates to Midwest markets for several forest products. This study considers rail, truck, and seaway shipping resources in a five-county area.

41. Carpenter, Eugene M. Canadian forest products shipped into the north-central region. Res. Pap. NC-83. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Experiment Station; 1972. 22 p.

This report summarizes trends in the importation of various forest products from Canada and approximates the volumes of these products that have a first destination within the north-central region.

42. Castle, E.N.; Youman, R.C. Economics in regional water research and policy. American Journal of Agricultural Economics. 50(5): 1655-1666; 1981.

Part I of this paper pertains to water resources and regional economic growth. Part II deals with choice indicators in public decisionmaking about investment in natural resources.

43. Chaffin, J. A.; Kushner, A. Important factors of forest industries on the economy of Georgia. Rep. 26. Macon, GA: Forest Research Council; 1971: 22.

Characterizes the role of the forest industry in Georgia for 1958 and 1967. Characteristics include: employment, payrolls, and value added. Forest products manufacturing ranks third in importance relative to other Georgia industries.

44. Chang, Sun Joseph; Buongiorno, Joseph. A programming model for multiple use forestry. Journal of Environmental Management. 13: 45-58; 1981.

A methodology of resource allocation combining goal programming and input-output analysis to provide a solution to the problem of multiple use planning on public forests. The model allows managers to specify the exact goal level for each management activity, to experiment with varying degrees of management intensity, to explore the outcome of different management assignments, and to determine the tradeoff between management activities.

45. Chappelle, D.E. Linear programming for forestry planning. In: Convery, Frank; Ralston, Charles, eds. Forestry and long range planning: Durham, NC: Duke University, School of Forestry and Environmental Studies; 1977: 129-163.

This paper provides (1) a simplified and concise description of linear programming, (2) a description of how linear programming has been used in forestry planning, and (3) a discussion of the advantages and disadvantages of linear programming in forestry planning.

46. Chase Econometric Association, Inc., Economic Research Service. Rural impacts of monetary policy. Agricultural Economic Research. 33(4): 1-11; 1981.

Responses to changes in national monetary policy vary regionally. Urban areas tend to be more responsive than rural areas. Some areas appear immune to national trends and can experience growth during a national credit crunch.

Chatterji, M. Space, location and regional development. In: Proceedings of a symposium; 1976 university symposium on regional science; London. London and New York: Academic Press; 1976. 239 p.

pers are by economists, geographers, and regional science experts on aspects of urban and regional planning and techniques used in regional science. Categories discussed include: growth and development patterns, spatial regularities and equilibrium models, urban transportation, welfare economics, and the environment.

Chinitz, B. Problems of regional economic development: discussion. American Economic Review. 68(2): 116; 1978.

The author argues that although it probably would be hard to project the flow of revenues and the impact of fiscal policy on migration and local economic activity in the Southwest, policymakers should do well to study the Alaska model and its findings.

Cichetti, Charles J.; Seneca, Joseph; Davidson, Paul. The demand and supply of outdoor recreation: an econometric analysis. New Brunswick, NJ: Bureau of Economic Research, Rutgers - The State University; 1969. 310 p.

The authors describe an econometric model based on the 1965 survey of outdoor recreation activities and other Census Bureau data. Implications of predictions through the year 2000 are also considered.

Clark, Colin W. Mathematical bioeconomics: the optimal management of renewable resources. New York: John Wiley & Sons; 1976. 352 p. (A Wiley-Interscience Series).

The theory of renewable resource management is applied to the commercial fishery and forestry industries. Among the models discussed are the phase-plane analysis of dynamical systems and the economic aspects of resource management. Also discussed are discrete time models and extension of the theory to more complex biological models involving age structure and multispecies systems.

Clawson, Marion. Decision making in timber production, harvest and marketing. Res. Pap. R-4. Washington, DC: Resources for the Future; 1977. 127 p.

This paper describes the decisionmaking process in producing, harvesting, and marketing timber in the United States; the biological, economic, and management considerations; and the methods of analysis. Author suggests that future management of National Forests will be based more directly on economic considerations in the future than on biological considerations.

52. Clawson, Marion, ed. Research in forest economics and forest policy. In: Proceedings of a symposium on research in forest economics and forest policy; 1977 January 13-14; Washington, DC. Res. Pap. R-3. Washington, DC: Resources for the Future. 1977. 555 p.

53. Connaughton, Kent P.; McKillop, William. Estimation of "small area" multipliers for the wood processing sector: an econometric approach. Forest Science. 25(1): 7-20; 1979.

The primary objective of the study was to develop estimates of multipliers that could be used to gauge the effect on local employment and different levels of income in California. The analysis focused on individual counties in the northern California planning areas of the USDA Forest Service. A multisector econometric approach to multiplier estimation was adopted to bridge the gap between the aggregate economic base multiplier and the multisector input-output multiplier.

54. Conopask, J.V. 1978. A data-pooling approach to estimate employment multipliers for small regional economies. Tech. Bull. 1583. Washington, DC: U.S. Department of Agriculture, Economic Research Service; 1978. 31 p.

This study demonstrates a procedure for estimating disaggregated and lagged economic base multipliers for short to intermediate term forecasting models.

55. Conroy, Michael E. Alternative strategies for regional industrial diversification. *Journal of Regional Science*. 14(1): 31-40; 1974.

This paper considers the problem of choosing an optimal diversifying increment of industries for a regional economy. Three alternative approaches or strategies for choosing such increments are explored, first theoretically and then in terms of their significance for three U.S. cities that have histories of greater than average instability for comparable cities. The industries nationally most stable will yield the optimally diversifying industrial increments only under very limited conditions.

56. Convery, F.J. Unit planning and local economic impacts of alternative forest management practices. Tech. Pap. 1. Durham, NC: Duke University, School of Forestry; 1973. 27 p.

Describes the development of procedures for determining the effect of alternative forest management systems on the local economy (as measured by income, employment, and tax revenue) and their application to a case study based on an area in Tennessee.

57. Cumberland, John H.; Vanbeek, Fritz. Regional economic development objectives and subsidization of local industry. *Land Economics*. 43(3): 253-254; 1967.

Article discusses the pros and cons of subsidization by local governments and private interest groups. Economists have generally rejected subsidies as an unwarranted interference with the efficiency of resource allocation. The proponents of the practice argue that subsidization can be used as a means of neutralizing or reducing misallocation under certain conditions.

58. Cummings, R.G.; Schulze, W.D.; Mehr, A.R. Optimal municipal investment in boomtowns... an empirical analysis. *Journal of Environmental Economics and Management*. 5(3): 252-267; 1978.

The primary concern of this paper is the use of wage-infrastructure tradeoffs as a measure of the social benefits of municipal infrastructure in boomtowns. A regression based on pooled cross sectional and time series data for 26 towns in the Rocky Mountain region suggests that individuals will "tradeoff" a 1-percent increase in per capita stocks of municipal infrastructure for a 0.035-percent decline in wages. These results are then used to calculate "optimal" levels for an example boomtown.

59. Cunningham, J.P. An energetic model linking forest industry and ecosystems. Helsinki. *Communications Instituti Forestalis Fenniae*. 79.3; 1974. 51 p.

The author provides a theoretical foundation for examining interactions between human activities and the environment. The results of an empirical test of these principles involving the paper industry of Finland are described.

60. Dane, C.W. Truck, rail and water movement western softwood plywood and lumber. *Forest Products Journal*. 15(2): 91-92; 1965.

Analyzes movements in 1961 from and to the three western and eight Rocky Mountain States, including a comparison of costs for transporting western and southern softwoods.

61. Dane, C.W. Economics of softwood plant location. *Forest Products Journal*. 20(1): 16-18; 1970.

The paper discusses economic factors influencing geographical location of softwood plywood plants, costs of labor, transportation, and timber.

62. Darr, David R.; Fight, Roger D. Douglas County, Oregon...potential economic impacts of a changing timber resource base. Res. Pap. PNW-179. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1974. 41 p.

An input-output technique was used to estimate the impact of the following on sales: change in demand for forest products, change in Forest Service or Bureau of Land Management timber harvest, and a decline in private harvest offset by an increase in Forest Service and Bureau of Land Management harvest.

63. Davis, Lawrence S.; Lyon, Edward F.; Burkhardt, Harold. A spatial equilibrium analysis of the southern Appalachian hardwood lumber-using industry. *Forest Science*. 18(3): 247-260; 1972.

The organization and cost efficiency in wood utilization of the southern Appalachian hardwood-using industry was studied. Linear programming was used to analyze a multistage, integrated industrial structure. The least-cost organization of the industry under a variety of future economic conditions was forecast.



- Dean, Robert D.; Leahy, William H.; McKee, David L. Spatial economic theory. New York: Free Press; London: Collier-Macmillan; 1970. 365 p.
- Diamond, Joseph D.; Chappelle, Daniel E. Application of an input-output model based on secondary data in local planning: the case of Manistee County. Rep. 409. East Lansing, MI: Michigan State University, Agricultural Experiment Station; 1981. 15 p.
- The study objective was to evaluate the usefulness of a set of growth guidelines to local public and private planners in achieving more effective use of local resources. The paper focuses on Manistee County and assesses some economic-ecologic impacts of a woodpulp plant.
- Dickerman, Alan; Butze, Stanley. The potential of timber management to affect regional growth and stability. *Journal of Forestry*. 73(5): 268-269; 1975.
- A model was developed for the Pacific coast and western Montana relating personal income generated in 16 economic sectors to a matrix of expected transactions between sectors. Multipliers were computed by industry based on net exports from the region. A computer model was also developed to assess the impact of alternative harvest levels.
- Drake, Ronald; Randall, Stanley; Skinne, Michael. Evaluation of economic impacts of Forest Service programs in northern New Mexico: development of analytical tools. Berkeley, CA: Department of Agriculture, Economic Research Service, Southwest Resource Group; 1973. 154 p. Office report.
- Analytical methods for estimating economic impacts were developed and applied to seven case studies. The usefulness and limitations of the models were evaluated.
- Duerr, W.A.; Teeguarden, D.E.; Guttenberg, Sam. Decision making in forest resource management. *Journal of Forestry*. 66: 760-763; 1968.
- Describes decision theory with emphasis on the firm, the interdependence of decisions, and the problems of forecasting with uncertainty.
- Dutrow, George F. Shift-share analysis of southern forest industry, 1958-1967. *Forest Products Journal*. 22(12): 10-14; 1972.

Between 1958 and 1967, average growth rates for southern forest industries surpassed expansion rates for all manufacturing in the United States in terms of value added in production and new capital expenditures. Shift-share analysis and growth ratios reveal the amounts by which expansion of forest industries in the South exceeded growth of the same industries nationwide.

70. Dyer, Allen A.; Hof, John; Kelly, James; Crim, Sarah. Implications of goal programming in forest resource allocation. *Forest Science*. 25(4): 535-543; 1979.

The paper describes and evaluates the use of goal programming as a forest resource allocation model. Goal programming is compared with linear programming in terms of achieving Pareto optimal solutions.

71. Elsner, Gary H.; Oliveira, Ronald A. Predicting traffic load impact of alternative recreation developments. Res. Pap. PSW-96. U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1973. 11 p.

Describes how changes in traffic load as a result of expansion of recreation facilities may be predicted. Once the basic model has been established, development alternatives may be simulated to estimate probable traffic loads for each link of the road system. Estimates for six alternatives are illustrated for the Harney Peak area of South Dakota.

72. Enos, John L.; Griffi, Keith B. Planning development. London: Addison-Wesley Publishing Company; 1970. 262 p.

This book is concerned with the practical problems of planning policy in underdeveloped countries. The justification for planning is described, followed by an explanation of the characteristics, uses, and limitations of planning models.

73. Erickson, Rodney A. The spatial pattern of income generation in lead firm, growth area-linkage system. *Economic Geography*. 51(1): 16-26; 1975.

The spatial pattern of income generated by a large lead firm is examined by use of a case study of the Boeing Aerospace Company and its contribution to growth of the Puget Sound area from 1963 through 1968.

74. Faden, Arnold M. Economics of space and time: the measure-theoretic foundations of social science. Ames, IA: Iowa State University Press; 1977. 703 p.

Develops a "novel...approach to the economics of space, incorporating much of the classical economics of location in its modern framework." Examines the von Thunen optimization model which deals with minimization of overall transport costs subject to areal capacity and land use allotment constraints. Discusses interplant and inter-industry optimization problems, and the classical Weber problem dealing with choice of a plant location.

75. Ferguson, J.S. Wood chips and regional development. Australian Forestry. 36(1): 15-23; 1972.

Impact of a wood-chip project on the regional economy is examined using data from an input-output analysis of the economy of western Australia.

76. Field, David B. Goal programming for forest management. Forest Science. 19(2): 125-135; 1973.

Goal programming is a mathematical procedure for the determination of a plan of action that offers a minimum aggregate deviation from a set of quantitative goals. This paper presents the technical details of the goal programming model. Included is a review of its use and an illustration of a possible application to a forest management problem.

77. Finn, R. Forsund; Steiner, Strom. The generation of residual flows in Norway: an input-output approach. Journal of Environmental Economics and Management. 3(2): 129-141; 1976.

The generation of 35 kinds of residuals is analyzed by an input-output approach for the economy of Norway in 1977. The input-output model disclosed that exports from the pulp and paper, metals, and minerals sectors are the main contributors to the annual flow of residuals.

78. Flacco, Paul R. Projected income and employment impacts of a decline in the timber resource base of a highly timber-dependent economy. Corvallis, OR: Oregon State University; 1978. 76 p. M.S. thesis.

Analysis based on an existing primary input-output model and a household survey of Douglas County, Oregon. Direct and indirect impacts on nine income categories were measured.

79. Flick, W. A. Resource valuation and multiple use planning: an input-output approach. Syracuse, NY: State University of New York, College of Environmental Science and Forestry; 1972. Ph. D. dissertation.

Provides a quantitative input-output model for predicting the impact of changes in one activity on all other activities in the forest and a list of "decision values" for the resources of the forest, the values being implied by management decisions and stated in dollars.

80. Flick, Warren A. Resource flows and values. Tech. Note 276. Denver, CO: U.S. Department of the Interior, Bureau of Land Management; 1975. 35 p.

An input-output model of the Eugene District of the Bureau of Land Management was constructed. The "industry" sectors correspond to the five major resource programs of the district: timber, wildlife, recreation, roads, and air and water pollution.

81. Flick, Warren A.; Trench, Peter, III; Bowers John R. Regional analysis of forest industries: input-output methods. Forest Science. 26(4): 548-560; 1980.

This paper presents a package of methods used to build an input-output model of Alabama. The model is based on a combination of primary and secondary data, and the structure of the forest industries is highlighted.

82. Forestry and Forest Products Division. Geographic comparison of the economics of pulp production. In: Proceedings, 5th session Food and Agriculture Organization of the United Nations (FAO) Advisory Committee on pulp and paper; 1964 April 27-28; Rome, Italy. Rome: Food and Agriculture Organization of United Nations; 1964. 33 p.

Study of industrial plant location, wood supply, (including tree species mix), pulp marketing, and prices. Capital and manufacturing costs and returns were estimated.

8. Fowler, Kenneth. Impacts of projected timber harvests in Humboldt County. Berkeley, CA: University of California; 1974. 116 p. Ph. D. dissertation.

Five alternative timber cutting levels are projected for a 20-year period ending in 1992. Models are developed to estimate effects of social factors, including employment, assessed valuation, gross regional product, and the productive capacity of the forest. Social tradeoffs associated with various rates of resource use are presented.

8. Friedmann, John R.P. Locational aspects of economic development. Land Economics. 32: 213-227; 1956.

The spatial incidence of investment, production, distribution, and consumption activities is crucial to the effective functioning of the activities in an economy.

8. Fromer, R. Some problems of regional planning in forestry. Unasylva. 15(2): 81-87; 1961.

Describes problems of regional forestry planning. Describes economic regions and production zones.

8. Gamble, Hays B. The regional economic role of forest products industries. Journal of Forestry. 66(6): 462-466; 1968.

The purpose of this paper is to define explicitly the role of forest products industries in the economic life of communities.

8. Gane, M. Priorities in planning cost and benefit methodology and simulation with special reference to forestry and economic development in Trinidad. Inst. Pap. 42. Oxford, England: Commonwealth Forestry Institute, University of Oxford; 1969. 101 p.

Contains technical descriptions of models and simulation techniques used in cost-benefit analysis of the wood-based sector of the Trinidad economy.

8. Giarratani, F. Application of an interindustry supply model to energy issues. Environment and Planning A. 8(4): 447-454; 1976.

An interindustry model relating gross output to the availability of primary inputs is used to examine supply linkages associated with national

energy production. The results of calculations for U.S. data highlight the importance of extractive energy sectors in intermediate production, and they identify supplying sectors that have the potential for restricting output. The use of this model as a means to simulate impact of alternative energy allocation programs on gross output is discussed, and the results of one simulation are presented.

89. Giarratani, Frank; Maddy, James D.; Socher, Charles F. [and others]. Regional and interregional input-output analysis: an annotated bibliography. Morgantown, WV: University of West Virginia, West Virginia Library; 1976. 126 p.

An annotated bibliography covering the theoretical, conceptual, and applied literature on regional and interregional input-output analysis.

90. Gillis, William; Butcher, W. Regional income effects of roundwood exports compared to local processing in timber dependent counties of western Washington. Res. Cent. Circ. 0620. Pullman, WA: Washington State University, College of Agriculture; 1979. 21 p.

Describes an econometric technique for estimating the effects on income when exports of roundwood from the timber-dependent region of western Washington are restricted.

91. Gilmore, John S. Boom towns may hinder energy resource development. Science. 191: 535-539; 1976.

Gilmore argues that isolated rural communities cannot handle sudden industrialization and growth without help. Major assistance--often involving institutional change--should come from States. In Gilmore's model community, economic stability is achieved when "the basic sector and the public services sector are more or less in balance."

92. Girgig, M.A. The regional income and employment multiplier effects of a pulp and paper mill. Scottish Journal of Political Economy. 18(1): 31-48; 1971.

Describes a multiplier model, constructed to analyze the effects of a subregion of a major industrial project on income and employment. Illustrates some of the difficulties of estimating the multiplier effects on income, and especially on employment.



93. Goldin, K.D. Roads and recreation. *Land Economics*. 48(2): 115-124; 1972.

Describes the allocation and distribution of roads and recreational services.

94. Green, George R. Community size and agglomeration of trade, service, and other locally oriented industries. *Work. Pap. CWR* 5. St. Louis, MO: Washington University, Institute for Urban and Regional Studies; 1966. 31 p. Office report.

This study is the first attempt to determine whether agglomeration effects might be predictable. Author describes the results of a statistical test for the assumption that residentiary employment rises more in proportion to the growth of total employment than in proportion to the demand for a region's industrial output.

95. Gregersen, H.M. The Latin American contribution to United States forest products imports: problems and potentials for the exporter. *Forest Products Journal*. 21(3): 16-20; 1971.

Discusses reasons for the comparatively small trade in tropical hardwoods, especially problems related to limitation of economically available quantities of acceptable species, the quality of processing, and difficulties in shipping and marketing. Possible remedies are considered.

96. Gregersen, Hans M. The role of forestry in regional economic development: an alternative view. *Journal of Forestry*. 71(2): 98-99; 1973.

The author presents eight views on the role of forestry in regional economic development in response to Kromm's (150) view.

97. Gregory, G. Robinson. Forest and economic development in Latin America: a challenge for the American forestry profession. *Journal of Forestry*. 63: 83-88; 1965.

This article shows why forests can and should play an important role in the development of Latin America; it emphasizes the need for American forestry to rise to the challenge.

98. Gregory, G. Robinson. *Forest resource economics*. New York: Ronald Press; 1972. 548 p.

Chapter 16 discusses the economics of transportation costs.

99. Gronberg, Timothy J.; Meyer, Jack. Spatial pricing and its effect on product transportability. *Journal of Business*. 55(2): 269-280; 1982.

The issue of which resources to devote toward making a product more transportable is addressed within the standard and spatial pricing model of firm. The relationship between transportability and pricing mode is specifically examined.

100. Haalick, Henry A. The role of physical and non-physical determinants of resource access roads in National Forest transportation planning. Syracuse, NY: State University of New York, College of Forestry; 1975. 386 p. Ph. D. dissertation.

The nonphysical determinants are laws, regulations, orders, objectives, plans, studies, research, hearings, court actions, advisory committees, interest groups, the public, and economic factors. The physical determinants are geographic location, land surface, and terrain features. The author describes forest resources road characteristics, and transportation systems as they relate to National Forests.

101. Hagenstein, P.R. The location decision for primary wood-using industries in the northern Appalachians. *Dissertation Abstracts*. 24(2): 457; 1963.

Author discusses factors determining plant locations. Quantitative estimates (derived from interviews) of location requirements for plants specific sizes in the lumber, particle board, and pulp industries were used in constructing a model for selecting economically optimum plant location.

102. Hagenstein, P.R. The location decision for wood-using industries in the northern Appalachians. *Res. Pap. NE-16*. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station; 1964. 36 p.

Discusses the future location of the lumber, particle board, woodpulp, and furniture industries in relation to wood requirements, labor, and transportation.

103. Hamilton, H.R.; Goldstone, S.E.; Milliman, J.W.; [and others]. Systems simulation for regional analysis: an application to river-basin planning. Cambridge, MA: M.I.T. Press; 1969. 407 p.

The purpose of this book is to explore how systems simulation may be applied to regional analyses. Although the actual model presented was developed within the context of river-basin analysis and planning, the findings of the research and the model developed are similar to other applications and may serve as a starting point for the construction of other regional simulation models.

104. Hamilton, T.E. Dimensions of the structure and performance in the Wisconsin pulpwood market. Dissertation Abstracts. 25(10): 5603; 1965.

Discusses efficiency of production and transportation and rate of profit for pulp and paper mills and for pulpwood producers and intermediate market agents.

105. Hamilton, T.E. Log export policy: theory vs. reality. Journal of Forestry. 69(8): 494-497; 1971.

Discusses economic theory regarding exports, U.S. economic statistics for 1961-69, national objectives and export policies, and some special characteristics of the forest products industry in relation to the controversy over increasing log exports to Japan.

106. Hammon, G.A.; McDonald, J.K. Recreation information management. Trends in Parks and Recreation. 4(2): 29-32; 1967.

Describes a recreation information management system, called RIM, that provides a detailed picture of where and when recreation use occurs on National Forest lands in relation to planned capacity. The system provides a wide variety of descriptive data such as the biological, physical, and esthetic characteristics of land and water units.

107. Hansen, Niles M., ed. Public policy and regional economic development: the experience of nine western countries. Cambridge, MA: Ballinger; 1974. 354 p.

Collection of 10 papers, each dealing with the following topics: general regional tendencies, policy issues and goals, regional development

policies and tools for their implementation, evaluation of policies, and indications of likely future directions of regional policy.

108. Hartman, L.M. Simulating a regional economy. Back, W.B.; and Waldrop, John E., Jr., eds. Regional studies of income distribution. Baton Rouge, LA: Louisiana State University; 1966: 83-88.

The objective of this paper is to indicate a tentative formulation of a regional simulation model for studying the effects of government programs on distribution of income. The model attempts to show procedural steps for computer programs to reproduce certain aspects of a regional economy over time.

109. Haynes, Richard W. A dynamic spatial-equilibrium model of the softwood timber economy with demand equations specified. Raleigh, NC: North Carolina State University; 1975. 109 p. Ph. D. dissertation.

A model for estimating changes in product prices and processing-plant locations resulting from changes in the geographic pattern of the U.S. softwood timber output.

110. Herrick, Owen W. Delimiting regional sub-areas for studies of timber-resource based activity in the Northeast. Forest Science. 19(3): 180-189; 1973.

The Northeast is classified into homogeneous subareas based on a variety of physical, economic, and demographic variables postulated to reflect conditions underlying timber-based activity in the region. Factor and cluster analyses provided efficient and objective procedures for classifying this extensive and complex region.

111. Hewings, Geoffrey J.D. Regional industrial analysis and development. The field of geography series. New York: St. Martin's Press; 1977. 180 p.

Describes the economic base and trade-flow analysis, the input-output analysis, theories of regional economic growth and public policy, and the problem of implementing development guidelines.

112. Hill, Forest G. Regional aspects of economic development. Land Economics. 38(2): 85-93; 1962.

Describes how regional development helps to shape and is shaped by national development, how national economic policy has differential effects on regions, and why policy should be adapted to regional conditions.

113. Hirsch, W.Z. Regional information design for public decisions. Review of Income and Wealth. 15(4): 369-380; 1961.

Key characteristics of regional accounts and regional information systems of relevance primarily at the State or Province level are examined first. Then the nature and scope of regional decisions are reviewed. Finally, one regional information design is sketched; it classifies the environmental and program information useful in regional decisionmaking.

114. Hirsch, Werner Z.; Sonenblum, Sidney. Selecting regional information for government planning and decision-making. Praeger special studies in U.S. economic and social development. New York: Praeger; 1970. 198 p. Published in cooperation with Los Angeles, CA: University of California, Institute of Government and Public Affairs.

Outlines a "subnational information design (SID) that will facilitate improved (economic policy) decisions at the state and local levels." Describes the construction, mechanics, and uses of such an information retrieval system by urban and other regional decisionmakers.

115. Holland, I.I. Foreign trade in forest products from the point of view of the importing country: the United States. Journal of Forestry. 60(8): 538-545; 1962.

Examines U.S. import position with Canada and suggests possible future trends.

116. Holland, I.I.; Judge, G.G. Estimated interregional flows of hardwood and softwood lumber. Journal of Forestry. 61(7): 488-497; 1963.

This study attempts to describe separately the distribution of hardwood and softwood lumber in 1958--under optimum conditions of minimum total transportation costs.

117. Holley, L.D. Location of the softwood plywood and lumber industries: a regional programming analysis. Land Economics. 46(2): 127-137; 1970.

A linear programming model demonstrates that the location of lumber and plywood production in the United States is inefficient and unstable. The plywood shift to the South is a move toward equilibrium. Results of the model justify more intensive forest management in the South than in any other region.

118. Holley, Lester D. Regional aspects of long-range planning in forestry. In: Convery, Frank; Ralston, Charles, eds. Forestry and long-range planning. Durham, NC: Duke University, School of Forestry and Environmental Studies; 1977: 75-78.

The objective of this paper is to discuss some of the regional aspects of planning the production and consumption of timber and timber products.

119. Hopkins, F.E. Transportation cost and industrial location: an analysis of the household furniture industry. Journal of Regional Science. 12(2): 261-277; 1972.

This article includes a discussion of the effect of transportation cost on industrial location. A model was used to investigate the level of employment and rate of change in employment in the household furniture industry between 1964 and 1968 at the county level for the continental United States.

120. Hughes, Jay. Forestry in Itasca County's economy: an input-output analysis. Misc. Rep. 95. St. Paul, MN: University of Minnesota, Agricultural Experiment Station; 1970. 98 p.

The publication uses an input-output framework for analyzing the impacts of changes in the level of activity associated with the timber resources of Itasca County. A 39- by 39-sector model was used. Transactions tables, technical coefficients, and expenditure multipliers are presented. Discusses the multiplier effect and what it means and does not mean for the planning process.



21. Hultman, Charles W. Exports and economic growth: a survey. *Land Economics*. 43(2): 148-157; 1967.

Article discusses and compares several models that have been advanced to describe the method and extent to which external trade has facilitated economic growth of regions or nations. Among the important approaches are: (a) the foreign trade multiplier models, (b) the "growth" models, (c) the leading sector, (d) the staple model, (e) the export base, and (f) the development stages (or location theory).

22. Hwang, Henry H.; Maki, Wilbur R. User's guide to the Minnesota two-region input-output model. Staff Pap. Ser. P79-34. St. Paul, MN: University of Minnesota, Department of Agricultural and Applied Economics. 1979. 85 p.

23. Hyde, William F. Timber supply, land allocation and economic efficiency. Washington, DC: Resources for the Future; Baltimore: Johns Hopkins University Press; 1980. 224 p.

This book explains some of the economic theory that is relevant to modeling longrun timber supplies and the optimal allocation of forest land to timber production and to other uses, principally recreation. This analysis is applied to two case studies from the important Douglas-fir region (roughly the area of Oregon and Washington west of the Cascade Range) which produces one-quarter of the Nation's softwood timber.

24. Irland, Lloyd C. Wilderness economics and policy. Lexington, MA: Heath, Lexington Books; 1979. 225 p.

Author concludes that economics may be useful for studying the markets for products of wilderness areas, for clarifying the impact of decisions, for describing the costs and benefits of wilderness areas, and for aiding in setting preservation priorities.

125. Isard, Walter. Location and space-economy: a general theory relating to industrial location, market areas, land use, trade, and urban structure. Cambridge, MA: M.I.T. Press; 1956. 350 p.

This book is Isard's important initial contribution to spatial economics. Topics are general theories of location and space-economy, transport

inputs and related spatial concepts, the locational equilibrium of the firm, and an analysis of the market and supply area.

126. Isard, Walter. Methods of regional analysis: an introduction to regional science. The regional science study series. Cambridge, MA: M.I.T. Press; 1960. 784 p.

Author purports to refine the spatial and regional frameworks of the social science disciplines, especially economics, through the development of a more adequate general theory of location and space-economy.

127. Isard, Walter. General theory: social, political, economic and regional, with particular reference to decision making analysis. The regional science study series. Cambridge, MA: M.I.T. Press; 1969. 1,040 p.

Offers "a general theory on the social, political and economic structure of regions."

128. Isard, Walter. Some notes on the linkage of the ecologic and economic systems. *Papers, Regional Science Association*. 22: 85-96; 1969.

This paper discusses concepts relating to linkages between the economic and the ecologic systems and how these linkages could be analyzed.

129. Isard, Walter. Problems of regional economic development: discussion. *American Economic Review*. 68(2): 116-117; 1978.

The challenge centers around the development of an operational framework for deepening, in the study of an individual region, the analysis and projection of its connections with every other region in a system such as the U.S. system.

130. Isard, Walter; Van Zele, Roger. Practical regional science analysis for environmental management. *International Regional Science Review*. 1(1): 1-25; 1975.

Presents basic techniques for environmental management. Techniques discussed help describe and predict both economic and ecological consequences of alternative plans. But for techniques to be put to use, the political process must provide the values to be reflected in environmental decisions.

131. James, G.A.; Henle, R.K. Sampling procedures for estimating mass and dispersed types of recreation use on large areas. Res. Pap. SE-31. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station; 1968. 15 p.
132. Johansson, Per-olv. On regional effects of government policies in a small open economy. Scandinavian Journal of Economics. 83(4): 541-552; 1981.

A regional version of "disequilibrium" situations affects the shortrun impacts of government policies. The impacts of government are analyzed under flexible and fixed exchange rates.

133. Johnston, Warren E.; Elsner, Gary. Outdoor recreation as a sector for economic development. 16th IUFRO World Congress (Div. 4), Oslo, 1976, (Place of publication unknown) (Publisher name unknown); p. 110-121. 1976.

Concludes that data amassed from a "systems" viewpoint is required for assessing the applicability of outdoor recreation-oriented programs in fulfilling economic development.

134. Jones, Barclay G.; Ragatz, Richard L.; Vathauikul, P. Regional analysis for economic development. Ithaca, NY: Cornell University, Division of Urban Studies, Center for Housing and Environmental Studies; 1964. 143 p.

The purpose of this study is to consider the economic development problem of Schoharie County, New York, in a broad general framework of similar kinds of problems that characterize many rural counties in this country.

135. Jones, Clifford D., Jr. Input-output analysis applied to rural resource development planning. ESCS-14. Washington, DC: U.S. Department of Agriculture, Economic Statistical and Cooperative Service; 1978. 94 p.

The use of an input-output model for estimating the economic impact of resource conservation and small watershed projects is illustrated.

136. Kaiser, H.F., Jr. Interindustry model of the U.S. forest products economy. Forest Products Journal. 18(11): 15-18; 1968.

An input-output model is developed to show the flow of goods through the forest products industry economy. Data from 1963 Census of Manufactures (227) are used to analyze each forest industry's contribution to the economy. Calculations were also made to determine direct and indirect effects of an increase in final demand for each industrial sector.

137. Kaiser, H.F., Jr. Input-output analysis of the southern forest economy, 1963. Res. Pap. SO-43. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station; 1969. 18 p.

Analysis of data from the 1963 Census of Manufactures (227) indicates that primary processing industries produce \$5,126 million worth of output and purchase stumpage costing \$335 million. Secondary processing industries converted a portion of this output into products worth \$3,36 million. Collectively, forest related industries paid \$2,181 million in wages to southerners.

138. Kaiser, H.F., Jr. Multi-regional input-output model for forest resource analysis. Forest Science. 18(1): 46-53; 1972.

An input-output model is developed to show the flow of goods through the forest products economy. Calculations also show direct and indirect effects of an increase in final demand for each industrial sector.

139. Kallio, Edwin; Dickerhoof, Edward H. Business and economic information available for market planning. Forest Products Journal. 29(10): 61-66; 1979.

Literature on forest products and their markets is expanding rapidly. The business manager must know where and how to select appropriate sources of information. Library reference sources and computer systems can help find the latest information on current and future products, production methods and markets.

10. Kalter, Robert J.; Lord, William B. Measurement of the impact of recreation investments on a local economy. *American Journal of Agricultural Economics*. 50(2): 243-256; 1968.

from-to type of interindustry model is formulated and empirically implemented to quantify local economic impacts of expenditures resulting from outdoor recreation. Direct, indirect, and induced sales, income, and employment impacts are derived; and multiplier values are calculated. Relationships among the from-to model, supplemental studies, and the analysis of regional benefits from governmental investment decisions are discussed.

11. Kennedy, J.J., Jr. The economic impact of outdoor recreation activities on a rural area economy: an input-output approach. University Park, PA: Pennsylvania State University; 1966. M.S. thesis.

12. King, K.F.S. Conflicting demands for land-economic factors and their reconciliation. *Unasylva*. 19(4): 195-199, 202; 1965.

Discusses economic and noneconomic factors for land use decisionmaking, including supply and demand, labor requirements, market location, and industrial crop possibilities.

13. Kirby, Malcolm. Land use planning, transportation planning, and integer programming. In: *Systems analysis and forest resource management; Proceedings of a workshop; SAF Systems Analysis Working Group. Society of American Foresters; 1975 August 11-13; University of Georgia, Athens, GA. Athens, GA: University of Georgia; 1976: 271-284.*

Suggests the potential range of applications of mathematical programming to planning problems in land use and transportation.

14. Klaassen, L.H.; Paelinck, J.H.P.; Wagenaar, S. Spatial systems: a general introduction. Westmead, England: Teakfield, Saxon House; 1979. 165 p. Netherlands Economic Institute, Studies in Spatial Analysis Series.

Discusses the advantages of "integral approaches" to planning that recognize the interrelationships among sectors of the regional economy and develops the concept of "potential access" to employment and other economic opportunities, linking it to the construction of a spatial welfare function.

145. Klein, E.L.; Fogg, P.J. Marketing practices of Louisiana sawmills. *Wood Util. Note*. Baton Rouge, LA: Louisiana State University, School of Forestry; 20: 4; 1970.

Provides general information on sources of logs, sales locations, and marketing channels.

146. Knetsch, J.L. Forest recreation: a case of non-market resource use. *Journal of Forestry*. 65(2): 102-105; 1967.

Author points out that most forest-based recreation is provided outside traditional markets, and also describes a method of calculating recreation benefits based on travel cost data.

147. Kort, John R. The theory of economic stability differentials: analysis, reformulation, and empirical evidence. Knoxville, TN: University of Tennessee; 1979. Ph. D. dissertation.

The entropy measure of industrial diversification is used to examine variation in regional growth. A model of 106 standard metropolitan statistical areas, corrected for city-size variation, showed that diversification was one of the factors accounting for regional differences in economic instability.

148. Kort, John R. Regional economic instability and industrial diversification in the U.S. *Land Economics*. 57(4): 596-608; 1981.

The purpose of this paper is to test the relationship among the economic variables: diversification, economic instability, and city size. The model explains variations in regional economic instability.

149. Kresge, David T.; Seiver, D. Planning for a resource-rich region: the case of Alaska. *American Economic Review*. 68(2): 99-104; 1978.

Describes a model for estimating the regional economic impacts of resource development, and more specifically, for evaluating regional policies designed to deal with these impacts. The Alaska model offers an excellent laboratory for a general analysis of resource development.



150. Kromm, D.E. Limitations on the role of forestry in regional economic development. *Journal of Forestry*. 70(10): 630-633; 1972.

The author questions the role of forestry as a method of growth. The presentation is mainly qualitative rather than quantitative.

151. Kuklinski, Antoni; Kultalahti, Olli; Koskiahio, Briita, eds. Regional dynamics of socio-economic change. Tampere, Finland: Finnpublisher; Atlantic Highlands, NJ: Humanities Press; 1979. 547 p.

Methods and approaches to rules used to control socio-economic change in regional development. Focuses on the processes, methods, and approaches to regional planning policy in different countries.

152. Laurent, F.A.; Hite, J.C. Environmental planning: an economic analysis--application for the coastal zone. New York: Praeger Publishers; 1972. 155 p.

The book develops the body of economic logic applicable to resource problems in the coastal zone and diagnoses the problems as legitimate matters of economic concern.

153. Le Heron, R.B. Best practice firms and productivity changes in the Pacific Northwest plywood and veneer industry, 1960-1972: some regional growth implications. *Environment and Planning A*. 8(2): 163-172; 1976.

This study summarizes the results of an empirical investigation of regional development roles of best practice firms in the Pacific Northwest plywood and veneer industry. It examines interrelations between growth impacts of high productivity performance and output and employment change, and the relative growth impacts of high productivity, best practice firms and less productive, nonbest practice firms.

154. Leuschner, William A. An econometric analysis of the Wisconsin aspen pulpwood market. *Forest Science*. 19(1): 41-46; 1973.

An econometric study of the short-term aspen pulpwood market in Wisconsin is described. The choice of variables entering the mathematical model, the method of parameter estimation, and results of the analysis are discussed.

155. Leven, Charles L. The economic base and regional growth. In: Maki, W.R.; Berry, B.J.L., eds. Research and education for regional and area development. Ames, IA: Iowa State University Press; 1966: 79-94.

Discusses the base theory of regional growth. Author examines what the economic base should theoretically include. The relationship between the neoclassical stages of growth theory is related to the growth of the economic base.

156. Leven, Charles L.; Legler, John B.; Shapiro, Perry. An analytical framework for regional development policy. Cambridge, MA: M.I.T. Press; 1970. 192 p.

This book establishes criteria for the definition and the number of output and final demand sectors and for the degree of industrial disaggregation in the production and resource accounts.

157. Leven, Charles L.; Legler, John B.; Shapiro, Perry. Regional analysis problems. In: Kuklinski, Antoni R., ed. Regional information and regional planning. Amsterdam, Netherlands: Mouton Publishers; 1974. 389 p.

This paper is about the "empirically implementable analytical system" that could make an effective contribution to the problem of how to effectively account for the regional dimension in national economic development policy.

158. Linowes, R. Robert; Allensworth, Don T. States and land-use control. Praeger Special Studies in U.S. Economic, Social and Political Issues. New York, Praeger Publisher: 1975. 243 p.

Demonstrates the interrelationship of land-use controls and various public facilities and services such as highways, water, and control of air pollution. Discusses the role of State policies, particularly the influence of State institutions (legislature and courts), as well as public and private interests.

19. Lyon, Kenneth S. Mining of the forest and the time path of the price of timber. *Journal of Environmental Economics and Management*. 8(4): 330-344; 1980.

The paper analyzes the effect of transportation (site specific) costs and the effect of mining (depletion) of the forest on the time path of the price and the net price of timber in the forestry models. The models differ in that one has zero costs, the other has positive costs. For certain costs, the analyses yield the standard mining theory results. The paper concludes that the theory of the mine is useful for analyzing the time path of the price of timber.

20. Maki, Wilbur; Schallau, Con H.; Beuter, John H. Importance of timber-based employment to the economic base of the Douglas-fir region of Oregon, Washington, and northern California. Res. Note PNW-76. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1968. 6 p.

Degree of economic dependency on timber industries was estimated for 15 subareas of the Douglas-fir region of Washington, Oregon, and California. This analysis was part of a study of how the region's forest resources can better contribute to the economic growth and development of the region. Dependency, measured in terms of the percent of economic (or export) base employment accounted for by timber-dependent industries, ranged from 6.2 percent for the Seattle economic area to 99.4 percent for the Roseburg area. Timber-dependent industries accounted for approximately 45 percent of the Douglas-fir region's economic base employment.

21. Maki, Wilbur; Schweitzer, Dennis L. Importance of timber-based employment to the Douglas-fir region, 1959 to 1971. Res. Note PNW-196. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 11 p.

Contrary to substantial increases in total employment in the Douglas-fir region from 1959 to 1971, employment in timber-dependent industries declined slightly. Only 3 of the 14 economic areas in the region matched national gains in employment in these industries. Although economies that were highly dependent on timber in 1959 still were in 1971, in nearly every instance a smaller proportion of economic base employment was concentrated in the timber-dependent industries.

162. Manthy, R.S. Marketing pulpwood in the north central region. Dissertation Abstracts. 25(4): 2137-2138; 1964.

163. Manthy, R.S. Pulpwood procurement practices viewed by forest economist. Technical Papers of the American Pulpwood Association. Montgomery, AL; January 1966: 5-8.

Shows the interrelationships between the agents or institutions within the marketing system in the Southeastern United States, and discusses some implications for pulpwood producers.

164. Masser, A.N.; Brows, Peter, eds. Spatial representation and spatial interaction. Leiden; Boston: Martinus Nijhoff Publishing; 1978. 212 p.

This book draws together various related investigations regarding spatial interaction research and sets them in a general framework within which the problem of spatial representation is viewed as part of the general problem of aggregation.

165. Massie, M.R.C. Marketing timber products in selected areas of the north central region. Dissertation Abstracts. 26(8): 4147; 1966.

Includes information on procurement, methods of transporting raw material and distances covered, profits, and changes in marketing practices that might increase marketing efficiency.

166. Mathur, Vija. Spatial economic theory of pollution control. *Journal of Environmental Economics and Management*. 3(1): 16-28; 1975.

The spatial theory of the firm presented in this paper casts doubt on the efficacy of a pollution tax to achieve the desired goal of the administration to tax sulfur oxide emissions over and above the Federal standard for electric powerplants.

167. McConnen, Richard J. The use and development of America's forest resources. *Economic Botany*. 21(1): 2-14; 1967.

The increased importance of recreation, water, and other multiple uses will have a great influence on the development and use of forest lands.

168. McConnen, Richard J.; Navon, Daniel I.; Amidon, Elliot. Efficient development and use of forest lands: an outline of a prototype computer-oriented system for operational planning. Forestry Commission (London), Forest Record. 59: 18-32; 1966.

The prototype system consists of a computer-oriented system called MIADS--an analytical model in linear programming format--and solutions for this model; also, auxiliary computer programs to update resource inventory information.

169. McKillop, William; Mead, Walter, eds. Timber policy issues in British Columbia. Vancouver, BC: University of British Columbia; 1974. 277 p.

This book was developed from a conference on British Columbia timber policy held in Vancouver. The articles fall into three sections: (1) goals, conflicts, and opportunities; (2) perspectives in resource administration; and (3) determining management priorities.

170. Meadows, John Crawford. Some approaches to considering the impact of forest based industries on the southern economy--an examination of growth using some comparative static models. Durham, NC: Duke University; 1970. 463 p. Ph. D. dissertation.

Study examines some of the possible approaches to considering the potential contribution forest-based industries make to regional growth. The region considered is the Southeastern United States, a region with distinctly low levels of economic activity and, according to most measures, relatively abundant forest resources.

171. Michigan Department of Commerce. A 44-sector input-output model of the Michigan economy. Lansing, MI: Michigan Department of Commerce, Energy Administration; 1980. 20 p. (Energy issue analysis series).

A 44-sector model of the Michigan economy is presented. By use of Hwang and Maki's (122) method, national statistics are split into Michigan and the rest of the Nation. A table was developed primarily for the consideration of energy issues.

172. Miernyk, William H. Long range forecasting with a regional input-output model. Western Economic Journal. 6(3): 165-176; 1968.

Discusses method for constructing a regional input-output table that uses location quotient for regional forecasting.

173. Moody, Harold T.; Puffer, Frank W. A goods regional product approach to regional modeling. Western Economic Journal. 7(3): 391-402; 1969.

Authors attempt to evaluate the usefulness of regional income and product accounts in the analysis of regional economy. The introduction of the demographic and income sectors allows some exploration of regional interactions.

174. Moore, B.C.; Rhodes, J. Regional economic policy and the movement of manufacturing firms to development areas. Economica. 43(169): 17-31; 1976.

Provides information on one of the major mechanisms for creating employment in regions with high unemployment. Regression analysis is used to estimate the impact of different instruments of regional policy on the number of new firms moving into development areas.

175. Morey, Edward R. The demand for site-specific recreational activities: a characteristic approach. Journal of Environmental Economics and Management. 8(4): 345-371; 1981.

A model of constrained utility maximizing behavior is developed to explain how a representative individual allocates ski days among alternative sites. A multinomial logit model of skier behavior is also developed, and maximum likelihood estimates of its parameters are obtained.

176. Moroney, John R. Natural resource endowment and comparative labor costs: a hybrid model of comparative advantage. Journal of Regional Science. 15: 130-150; 1975.

The paper first presents a synthesis of two theories that have historically been treated as alternative explanations of comparative advantage, then it uses a simplified hybrid model to partially explain why the low-wage southern region of the United States produces large concentrations of certain capital intensive goods.



Murray, James M.; Harris, James J. A regional economic analysis of the Turtle Mountain Indian Reservation: determining potential for commercial development. Minneapolis, MN: Prepared for Federal Reserve Bank of Minneapolis; 1978. 26 p. (Ninth District Economic Information Series).

economic base model and the threshold analysis technique are used to examine opportunities for business expansion.

Nashlund, B. The principle of sustained yield and forest management. Scandinavian Journal of Economics. 79(1): 1-7; 1977.

For several reasons, it seems reasonable to base analysis of optimal forest management on a principle of a guaranteed longrun supply of wood. Optimal policies for forest management (fertilization, thinning, rotation) can thereby be determined with less reliance on estimates of future prices. Optimal control theory is applied, and the use of the adjoint variable for economic information is discussed.

Navon, Daniel I. Short-run and long-run models for planning forest transportation. In: Systems analysis and forest resource management: Proceedings of a workshop; Society of American Foresters Systems Analysis Working Group: Society of American Foresters; 1975 August 11-13; University of Georgia, Athens, Ga. Athens, GA: University of Georgia; 1976: 300-312.

Describes two models for attacking short- and long-range planning problems of an integrated forest enterprise that sells logs delivered to the mill gate.

Needleman, L., eds. Regional analysis: selected readings. London: Penguin Books, Ltd.; 1968. 395 p.

Selections are concerned specifically with the economic aspects of regional science and especially with the techniques of regional economic analysis.

Norman, George. Economies of scale, transport costs and location. Studies in Applied Regional Science 16. Boston: Martinus Nijhoff; 1979. 205 p.

Employs mathematical programming and activity analysis techniques to examine industrial spatial

choice decisions in a world in which production units are allowed to operate in nonconvex regions of their total cost-curves.

182. North, Douglas J. Location theory and regional economic growth. Journal of Political Economy. 63: 240-255; 1955.

To understand the growth of regions, according to North, one must understand the rate of growth of the export base. As the income in a region grows and transfer costs become less significant, the region will export goods and services once produced solely for local consumption. This leads to diversification of the export base and ultimately causes local economies "to lose their identity as regions" (224).

183. Oliveira, Ronald A. Systems analysis in land use planning...a conceptual development. Gen. Tech. Rep. PSW-5. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1973. 8 p.

Describes the general structures of a land use decision model approached through systems analysis, with an example of its application on a USDA Forest Service Ranger District.

184. Osteen, Craig D. An application of a linear programming model to spatial planning of forest resources in the Kalamazoo River basin of Michigan. East Lansing, MI: Michigan State University; 1976. 350 p. Ph. D. dissertation.

The objective of the study is to examine the feasibility of building an integrated land inventory and evaluation system for river basin planning studies. The location aspect of the model is emphasized.

185. Osteen, Craig D.; Chappelle, Daniel E. Forest resource management options for Kalamazoo River basin. Res. Pap. 404. East Lansing, MI: Michigan State University, Agricultural Experiment Station; 1981. 12 p.

This research report provides land management guidelines for three interdependent forest resource concerns in the Kalamazoo River basin: (1) increasing production from nonindustrial, privately owned woodlands; (2) maintaining or increasing wildlife; and (3) protecting water quality.

186. Paelinck, Jean H.P.; Klaassen, Leo H. [and others]. Spatial econometrics. Westmead, England: Teakfield, Saxon House; 1979. 211 p. (Netherlands Economic Institute, Studies in Spatial Analysis Series).

Introduces the general principles of the econometric modeling of phenomenon characterized by spatial interdependence. Treats problems of specification, identification, estimation, and hypothesis testing and provides empirical results illustrating basic concepts.

187. Palmini, Dennis J. The secondary impact of non-point pollution control: a linear programming/input-output analysis. *Journal of Environmental Economics and Management*. 9(3): 263-278; 1981.

A joint linear-programming interindustry model is used to estimate the impact on small regional economies of nonpoint pollution controls of agriculture. Results from the linear-programming submodel of the farm production sector of a region are entered as final demand changes in the "rows-only" interindustry model of the regional economy. Emphasis is placed on describing the models and the linkages between them and on evaluating the usefulness and limitations of the modeling approach. A brief review of empirical results is also given.

188. Park, Se-Hark; Mohtadi, Malek; Kubursi, Atif. Errors in regional nonsurvey input-output models: analytical and simulation results. *Journal of Regional Science*. 21(3): 321-339; 1981.

This paper derives analytical error functions that specify mathematically the error functions associated with the use of a nonsurvey input-output table that would be unknown without a study.

189. Pillai, N.G. Regional development and economic growth, problems, analysis and policies. Selected bibliography. Ottawa, ON: Department of Regional Economic Expansion; 1969. 285 p.

Lists books, pamphlets, and journals on many topics including regional development and economic growth.

190. Pleeter, Saul, ed. Economic impact analysis: methodology and applications. *Studies in Applied Regional Science* 19. Boston: Martinus Nijhoff; 1979. 196 p.

Reviews basic regional models and foundations of the economic base model, and discusses input-output models. Also discusses application of regional models, such as econometric and regional input-output models for impact analysis and the multi-regional, multi-industry forecast model.

191. Richardson, Harry W. The state of regional economics: a survey article. *International Science Review*. 3(1): 1-48; 1978.

This paper reviews three categories of regional economics research: theory, methods, and policy. Author suggests that many of the unresolved questions in regional economics overlap disciplinary boundaries and require the interdisciplinary skills of regional science rather than those of mainstream economics.

192. Risbrudt, Christopher. Past and future technological change in the U.S. forest industries. East Lansing, MI: Michigan State University; 1979. Ph. D. dissertation.

The author examines technological change in the forest industries covered by SIC codes 2411, 2421, 2611, and 2621. Qualitative and econometric measurements are used.

193. Roberts, R.B.; Fishkind, H. The role of monetary forces in regional economic activity: an econometric simulation analysis. *Journal of Regional Science*. 19(1): 15-29; 1979.

The simulation analysis indicates that regional econometric models that exclude considerations of regional financial markets are capable of reasonable simulation behavior and can produce adequate forecasts. A more structural model, however, that explicitly allows for regional financial markets can provide greater accuracy.

- Rose, Adam; Nakayama, Benand; Stevens, Brandt. Modern energy region development and income distribution: an input-output analysis. *Journal of Environmental Economics and Management*. 9(2): 149-164; 1982.
- This paper formulates an input-output method for determining the distributional consequences of energy development projects. An analysis of thermal energy development in Imperial County, California, is presented. Results indicate that equality of personal incomes is likely to decrease by several percentage points as measured by the Gini Coefficient. Sensitivity of the results is examined for important factors such as supply elasticities, preferential employment of local residents, and concentration of land holdings.
- Ross, Peggy J.; Bluestone, Herman; Hine, Fred K. Indicators of social well-being for U.S. counties. *Rural Dev. Res. Rep.* 10. Washington, DC: U.S. Department of Agriculture, Economics, Statistics, and Cooperatives Service; 1979. 18 p.
- This report describes how four composite indexes of social well-being for 3,097 U.S. counties were constructed. These indexes--socio-economic, health, family status, and alienation--are selected by U.S. county maps and through mean index scores of counties grouped by metro-nonmetro status and rural-urban orientation.
- Row, Clark. Regional competition in softwood lumber. *Society of American Foresters proceedings* 1962. Washington, DC; 1963: 97-103.
- This widespread internal change of the last decade will continue. Increased timber supplies, trends in regional production and freight costs, characteristics of lumber species in relation to demand, and the shifting geography of lumber consumption for the western pine region, Southern States and the Mississippi, and Canadian imports.
- Russell, Robert M. WRIS: a resource information system for wildland management. *Res. Pap. PSW-107*. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1975. 12 p.
- This provides a means of collecting, processing, storing, retrieving, updating, and displaying geographic data and makes possible the performance of logical operations on these data.
198. Sartorius, Peter; Henl, Hans. Forestry and economic development. *Praeger special studies in international economics and development*. New York: Frederick A. Praeger; 1968. 340 p.
- Discusses the role of forestry in rural economics of both developed and underdeveloped countries and considers its relationship to economic development. Provides a general discussion of world lumber markets, manpower needs, and the possibilities of establishing forestry industries in the less developed countries.
199. Schallau, Con H; Maki, Wilbur; Beuter, John. Economic impact projections for alternative levels of timber production in the Douglas-fir region. *Annals of Regional Science*. 3(1): 96-106; 1969.
- The paper explores whether permanent forests, producing a sustained, even flow of timber, assure economic stability of timber-dependent communities; also, how sustained yield forestry affects employment and population in today's ever changing economy.
200. Schallau, Con H. An economic analysis of accelerated road construction on the Bureau of Land Management's Tillamook resource area. *Res. Pap. PNW-98*. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1970. 29 p.
- Acceleration of road construction in the Bureau of Land Management Tillamook resource area would not be economically feasible. Although doubling the current rate of construction would increase thinning yields, added stumpage revenues would not compensate for higher interest, timber sale administration, and maintenance charges. In fact, investment in such a plan would earn a minus 1.25-percent rate of return.
201. Schallau, Con H. Can regulation contribute to economic stability? *Journal of Forestry*. 72(4): 214-216; 1974.
- Examines the efficacy of strict adherence to nondeclining even-flow as a means of fostering economic stability of timber-dependent communities.



202. Schallau, Con H. Stages of growth theory and money flows from commercial banks in timber dependent communities. Res. Pap. PNW-279. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1980. 16 p.

The flow of funds from commercial banks in western Oregon may indicate how a timber short fall will affect community stability. Results suggest the inappropriateness of a single public forest management policy.

203. Schuster, Ervin G. Local economic impact: a decision variable in forest resource management: a study report. Missoula, MT: University of Montana, Montana Forest and Conservation Experiment Station, School of Forestry; 1976. 104 p.

This paper considers local economic impacts that result from changes in forest management decisions (for example, timber harvesting) in the Forest Service. The direct and indirect consequences, both short and long range, of these decisions is discussed.

204. Schuster, Ervin G.; Hatch, Charles; Koss, William. Location quotients, excess employment and short-run economic base multipliers for Idaho's forest products industry. Inf. Ser. 10. Moscow, ID: University of Idaho, Wildlife and Range Experiment Station; 1975. 25 p.

This paper focuses on three measures commonly used in the evaluation of alternatives: (a) location quotient, (b) excess employment, and (c) shortrun economic base multipliers.

205. Schuster, Ervin G.; Koss, William D.; Godfrey, E. Bruce. Employment and wages in Idaho's forest products industry. Inf. Ser. 5. Moscow: University of Idaho, Wildlife and Range Experiment Station; 1974. 48 p.

This paper focuses on selected characteristics of the forest products industry. It addresses questions about wages, employment, total sales, number of firms, and value added by the industry.

206. Serck-Hanssen, Jan. Optimal patterns of location. Contributions to Economic Analysis 66. Amsterdam; London: North-Holland; 1970. 235 p.

Discusses the conditions necessary for optimal spatial distribution and attempts to analyze the type of market mechanism that will bring about a optimal solution.

207. Shane, Mathew D. The flow of funds through the commercial banking system, Minnesota-North Dakota. Stn. Bull. 506. Minneapolis, MN: University of Minnesota Agricultural Experiment Station; 1972. 30 p.

Loan-to-deposit and correspondent balances ratios were used to examine how well commercial banks performed the task of transferring funds between regions and sectors. Evidence tended to support the hypothesis that rural area savings provide part of the capital for industrial-urban development.

208. Shechter, Mordechai; Lucas, Robert C. Simulation of recreational use for park and wilderness management. Baltimore: Johns Hopkins University Press for Resources for The Future; 1978. 220 p.

A simulation model is used to predict overall use patterns of new trails, trail closures, new camp areas, and new entry points, designed to preserve the wilderness aspect of public wilderness parks by restricting the number of people who may receive the benefit, while attempting to minimize the number of people excluded and the number of activities prohibited.

209. Siebert, H. Environment and regional growth. Zeitschrift National Economie. 33(1-2): 79-85; 1973. (In English).

A two-region model is constructed with the environment as one determinant of regional growth. It is assumed that production generates a pollutant as a byproduct and that pollution increases progressively with the level of output. The model indicates that in a spatial setting, a high level of pollution may cause a lower regional growth rate because labor is sensitive to environment quality.

210. Siebert, Horst. Regional economic growth: theory and policy. Scranton, PA. International Textbook Co.; 1969. 217 p.

Smith, Donald Mitchell. Neoclassical growth models and regional growth in the U.S. *Journal of Regional Science*. 15(2): 165-181; 1975.

Aggregate theory of growth was tested using for the States of the United States. Results showed that the growth experience of States since supports the aggregate theory of growth. Migration is in the direction hypothesized, capital movement provides indirect support for assumption that capital moves from State to in search of a higher return.

Smith, Kerry V. Congestion, travel cost recreational demand models and benefit evaluation. *Journal of Environmental Economics and Management*. 8(1): 92-96; 1978.

Treatment of congestion in travel cost demand models for recreational sites is a subject of considerable importance for both allocation and management of public lands. The most appropriate treatment of congestion requires that travel cost models be amended to reflect the effects of congestion on: (a) the modeling of individual behavior, (b) the estimation of individual demand for service for recreational sites, and (c) the description of how services for sites are allocated for individual users.

Snyder, Robert. An interregional analysis of the location of the pulp and paper industry in the western U.S. Corvallis, OR: Oregon State University; 1975. Ph. D. dissertation.

Soderland, J.R. Procedures in planning forest transportation systems with particular reference to the Pacific Northwest. Seattle, WA: University of Washington; 1968. M.S. thesis.

Steensen, D.H.J. A spatial equilibrium model of the wood-supply sheds for the pulp and paper industry in Alabama. Dissertation Abstracts. 27A(11): 3575; 1967.

A model was developed in which locations of processing plants were assumed to be fixed in space, whereas the boundaries of the supplying area (shed) associated with each plant were determined by the model.

216. Streeby, L.L. Role of the wood products industry in Oregon's economy. Corvallis, OR: Oregon State University; 1974. Ph. D. dissertation.

Estimates the contribution of the wood products industry to income and employment of the State of Oregon. Estimates contribution of the wood products industry to the income and employment of each of the following sections of the State: Astoria, Portland, Salem, Corvallis, Eugene, Roseburg, Coos Bay, and Medford areas, and eastern Oregon.

217. Streyffert, T. World pulpwood: a study in the competitive position of pulpwood in different forest regions. Stockholm: Almqvist and Wiksell; 1968. 213 p.

Primarily a study of the comparative cost of growing pulpwood and its harvesting and delivery to the mill. Part I includes regional and county studies grouped under tropical and subtropical zones, and temperate zones. Part II describes the economics of expansion in pulp and paper on a worldwide basis.

218. Stumbo, Donald A. Choosing forest products industries for community development planning. *Forest Products Journal*. 29(7): 16-22; 1979.

The study used a static linear-programming approach limited by annual growth of the forest resource for rural development planning. Three different goals were optimized: employment, income, and profit. Input-output data for each operation provided the necessary coefficients for all the functions. The data were obtained from individual studies of each operation to determine capital requirements, operating costs, return to the community, and production levels and prices.

219. Sutherland, Ronald J. A regional approach to estimating recreation benefits of improved water quality. *Journal of Environmental Economics and Management*. 9(3): 229-247; 1981.

Recreational demand and value are estimated by the travel-cost method for fishing, camping, boating, and swimming on a site-specific regional basis. The model is regional in that 179 sites are defined for the Pacific Northwest. A gravity model is used to estimate the number of trips from each destination in the region, and these data are the basic input in the travel-cost demand curves. The model is illustrated by estimating the recreation benefits that would result from meeting the national environmental goal of "fishable" and "swimmable" rivers. The main finding is that potential recreation benefits are concentrated in a few select areas that are accessible to large population centers.

220. Tarayama, T.; Judge, G.G. Equilibrium among spatially separated markets: a reformulation. *Econometrica*. 32(4): 510-524; 1964.

This paper reformulates the Samuelson model concerning competitive equilibrium among spatially separated markets. If the existence of linear regional demand and supply relations is assumed, the problem of interconnected competitive markets is converted into a quadratic programming problem, and a computational algorithm is specified that may be used to obtain directly and efficiently the optimal solution.

221. Teitz, Michael B. Technical and social basis for regional land use policy and planning. *Regional Science Association Papers*. 32:203-211; 1974.

The paper explores issues associated with land use policy and planning in the United States.

222. Thomas, Morgan C. The export base and development stages theories of regional economic growth: an appraisal. *Land Economics*. 40(4): 421-432; 1964.

This paper comments on various aspects that are pertinent to the understanding of regional economic growth. Some characteristics of the development stage and export stage, which provide insights about the process of economic growth, have been stressed. Both theories have many good attributes that could be developed and perhaps could be incorporated into a single theory of regional economic growth.

223. Thomas, Morgan C. Regional economic growth: some conceptual aspects. *Land Economics*. 45(1): 43-51; 1969.

The principal theories explaining the how and why of economic growth are the stages of development and the export base theories. Because of dissatisfaction with these theories, the author used elements from both to construct an alternative theory.

224. Tiebout, Charles M. Exports and regional economic growth. *Journal of Political Economics*. 64(2): 256-265; 1956.

Tiebout argues that export base is "merely one aspect of a general theory of short-run regional income determination." This discussion is the other half of the classic debate with Douglas North (182).

225. Tombaugh, L.W. The location of vacation homes in Michigan: a socio-economic study of environmental preferences. Ann Arbor, MI: University of Michigan; 1968. Ph. D. dissertation.

Using data from a canvas of nearly 1,200 vacation homeowners in Michigan, the author describes location patterns of vacation homes, the relationship between location and selected socio-economic variables, and probable future location patterns.

226. U.S. Department of Agriculture, Economic Research Service. Regional development and plan evaluation. The use of input-output analysis. *Agric. Handb.* 530. Washington, DC: U.S. Department of Agriculture; 1978. 128 p.

Examines the use of input-output models for evaluating water and related land resource plans prepared by the Federal Government. Input-output concepts are described and applied to a hypothetical project. A nonsurvey estimation technique for developing input-output models for small areas is also described.

227. U.S. Department of Commerce, Bureau of the Census. 1963 census of manufactures. Industry statistics, Vol. 2, pt. 1. Washington, DC: U.S. Government Printing Office; 1966.



U.S. Department of Commerce, Bureau of Economic Analysis, Regional Economic Analysis Division. Industry-specific gross output multipliers for BEA economic areas (RIMS). Washington, DC; 1977. 135 p.

Provides economic impact multipliers for 173 BEA (Bureau of Economic Analysis) economic areas and a description of how they can be used.

2. Ullman, Edward L.; Dacey, Michael F. The minimum requirements approach to the urban economic base. Paper and Proceedings, Regional Science Association; 1960: 6:176-194.

This paper offers an alternative method for understanding the urban employment structure. This method yields a quantitative statement that closely approximates the minimum percentage of a labor force required in various sectors of its economy to maintain viability of an urban area.

3. Valfer, Ernst S.; McWhinney, William N. Decision making in land management and the impact of socio-political problems. Berkeley, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station; 1970. 10 p.

Surveys the major decision fields in the Forest Service, the tasks and skills required for each, the relationship between the decisionmaking tasks and the character of the organization.

Van Delft, A.; Nijkamp, P. A multi-objective decision model for regional development, environmental quality control and industrial land use. Papers, Regional Science Association. 36: 35-57; 1976.

This paper aims to present a set of recently developed methods for making adequate policy decisions on the selection of regional economic activities. A central element in the paper is the combination of traditional optimization procedures (namely, linear programming techniques) and more recently developed multicriteria procedures (namely, a concordance analysis) to determine an optimal planning strategy.

232. Vining, Rutledge. Delimitation of economic areas: statistical concepts in the study of spatial structures. Journal of American Statistical Association. 48(261): 44-64; 1953.

The paper analyzes the concept of state economic areas: areas that are designated as "functional groupings of counties," each containing a "distinctive" economy.

233. Waggener, Thomas R. Community stability as a forest management objective. Journal of Forestry. 75(11): 710-714; 1977.

Author predicted that the National Forest Management Act of 1976 would spark renewed interest in community stability.

234. Wall, Brian R. Employment implications of projected timber output in the Douglas-fir region, 1917-2000. Res. Note PNW-211. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1973. 11 p.

Employment in the timber-based industries in the Douglas-fir region is projected to drop 45 percent between 1970 and the year 2000. Employment-wood consumption relationships are a major factor influencing employment projections, although declining timber production and a high level of log exports are also important.

235. Wall, Brian; Oswald, Daniel. A technique and relationships for projections of employment in the Pacific coast forest products industries. Res. Pap. PNW-189. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; 1975. 49 p.

The authors develop employment-raw material consumption ratios based on historical data for specified primary wood-using industries. Trends in total employment by geographic area and industrial sector, and slow changes in labor requirements and raw material input-product output are described. Employment-wood consumption ratios were used to predict future employment in some sectors of the forest products industry, given estimates of future wood consumption.

236. Wardle, P.A. The application of linear programming to problems of timber transport scheduling the supply to a pulp mill. Geneva, Switzerland: Food and Agriculture Organization of the United Nations Study Group on Methods of Organization of Forest Work; 1966. 7 p.

Exemplified by a study of optimum cutting programs for a group of British Forestry Commission forests at different distances from the pulp mill.

237. Weintraub, Andres; Navon, Daniel. A forest management planning model integrating silvicultural and transportation activities. *Management Science*. 22(12): 1299-1308; 1976.

A mixed integer linear programming model is used to integrate the long-range planning of silviculture, road construction and maintenance, and log-hauling activities for large forest management units.

238. Werczberger, E. A goal-programming model for industrial location involving environment considerations. *Environment and Planning A*. 8(2): 173-188; 1976.

This paper presents an application of goal programming to the planning of industrial location in the context of air pollution policy. Author first discusses the theoretical basis for goal programming and then presents the mathematical formulation and numerical evaluation of a hypothetical industrial location problem. Finally, goal programming is evaluated for its implications for environmental planning.

239. Wheeler, James O. Spatial changes in manufacturing: the Michigan example, 1840-1963. *Land Economics*. 47(2): 197-198; 1971.

Author illustrates the patterns of manufacturing change in the Lower Peninsula of Michigan and summarizes these changes for four major areas of technological development.

240. Will, Robert A. Federal influences on industrial location: how extensive? *Land Economics*. 40(1): 49-57; 1964.

Influence of Federal Government on plant location decision.

241. Williamson, Robert B. Simple input-output models for area economic analysis. *Land Economics*. 46(3): 333-338; 1970.

This study, using simple input-output models, attempts to find a practical, improved substitute for the economic base analysis technique.

242. Williamson, Robert B. Regional growth: predictive power of the export base theory. *Growth and Change*. 6(1): 3-10; 1975.

The primary purpose of this article is to present a survey of studies that contain empirical evidence on the export base theory. Presented first as background are a brief statement on the nature of the theory and some of the major conceptual issues pertaining to its use.

243. Willman, Elizabeth. The value of time in recreation benefit studies. *Journal of Environmental Economics and Management*. 7(3): 272-286; 1979.

This paper examines the role of time costs in models describing recreation behavior and draws implications for the travel-cost approach to estimating the benefits of recreation sites. The analysis shows that both recreation and travel time are costly.

244. Wilson, D.A. Comparative economics of management of close and distant lands. *Pulp and Paper Magazine Canada*. 64(4): WR194-WR197; 1963.

Discusses the economics of management of forest lands in Canada near to and far from markets.

245. Wilson, Holton J. Impact analysis and multiplier specification. *Growth and Change*. 8(3): 42-46; 1977.

The effect that the choice of multipliers can have on economic impact studies can be substantial. This is illustrated by the impact of the University of Tulsa on the economy of the Tulsa standard metropolitan statistical area (SMSA). Although this article focuses on a university, the concepts apply equally well to other types of export activities.

Yoho, J.G.; Muench, J.R. Regional economic factors bearing on the future of the lumber and woodpulp industries in the South. *Journal of Forestry*. 60(5): 312-319; 1962.

study considers factors that might influence the course of industrial forestry in the South. These are the forces of population, labor, income, use, and some of the cost-price aspects of the lumber and woodpulp industries.

Youmans, Russell C.; Darr, David R.; Fight, Roger; [and others]. Douglas County, Oregon...structure of a timber county economy. Circ. Inf. 645. Corvallis, OR: Oregon State University, Agricultural Experiment Station; 1974. 24 p.

input-output technique is used to show how the economic sectors in Douglas County relate to each other. Special emphasis is given to the timber processing industries, the Bureau of Land Management, and the USDA Forest Service. Timber processing industries account for 63 percent of the exports of the county.

Youngday, D.J.; Fight, R.D. Natural resources policy: the distributional impact on consumers of changing output prices. *Land Economics*. 55(1): 11-17; 1979.

input-output methodology is developed to examine the impact of natural resource policy on output prices and the real distribution of (given) principal incomes. A measure of welfare change is constructed for individual households; it yields the distributional impact of price changes. An application to forest products suggests that policies resulting in higher consumer prices are regressive.

Zinn, Gary W. A model for analyzing the contributions of forestry to a region. Syracuse, NY: University of New York, College of Environmental Science and Forestry; 1972. 268 p. Ph. D. dissertation.

This study develops a model for comprehensively analyzing the present contribution of forestry to the regional economy. Author describes the accepted general principles of regional development that form the background and bases for the model. Explains how the model can be combined with other techniques to aid efficient planning for regional development and discusses and illustrates the application of the model to the Appalachian region of New York State.

250. Zinn, Gary W. Regional development and forest resource management. *Journal of Forestry*. 73(5): 287, 305; 1975.

Social and economic development do not necessarily depend directly on economic growth. Recognition of this fact is producing changes in public attitudes and policies regarding the objectives and nature of economic activity. These changes, in turn, are creating a new and greatly expanded framework for decisionmaking in many contexts, including forestry. Thus, it behooves the profession to understand and adjust to the situation.

251. Zivnуска, J.A. The integration of forest development plans and national development plans: how to make the forestry case at the national level. In: 1966 Proceedings, 6th World Forestry Congress; Rome, Italy. Rome: Food and Agriculture Organization of the United Nations; 1968: 557-566.

A general model of economic growth in labor-surplus underdeveloped nations is presented. This model is used to demonstrate that forest development can often be very useful in facilitating the desired structural shifts in the economy because the forest industries sector in many of its major characteristics represents an intermediate state between the agricultural sector and the general industrial sector.



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Obiya, Alex; Chappelle, Daniel E.; Schallau, Con H.  
Spatial and regional analysis methods in  
forestry economics: an annotated bibliography.  
Gen. Tech. Rep. PNW-190. Portland, OR: U.S.  
Department of Agriculture, Forest Service,  
Pacific Northwest Research Station; 1986. 32 p.

This bibliography provides extensive coverage of a relatively new field of study. Entries relate to models, techniques, and information regarding spatial and regional analysis printed before 1981.

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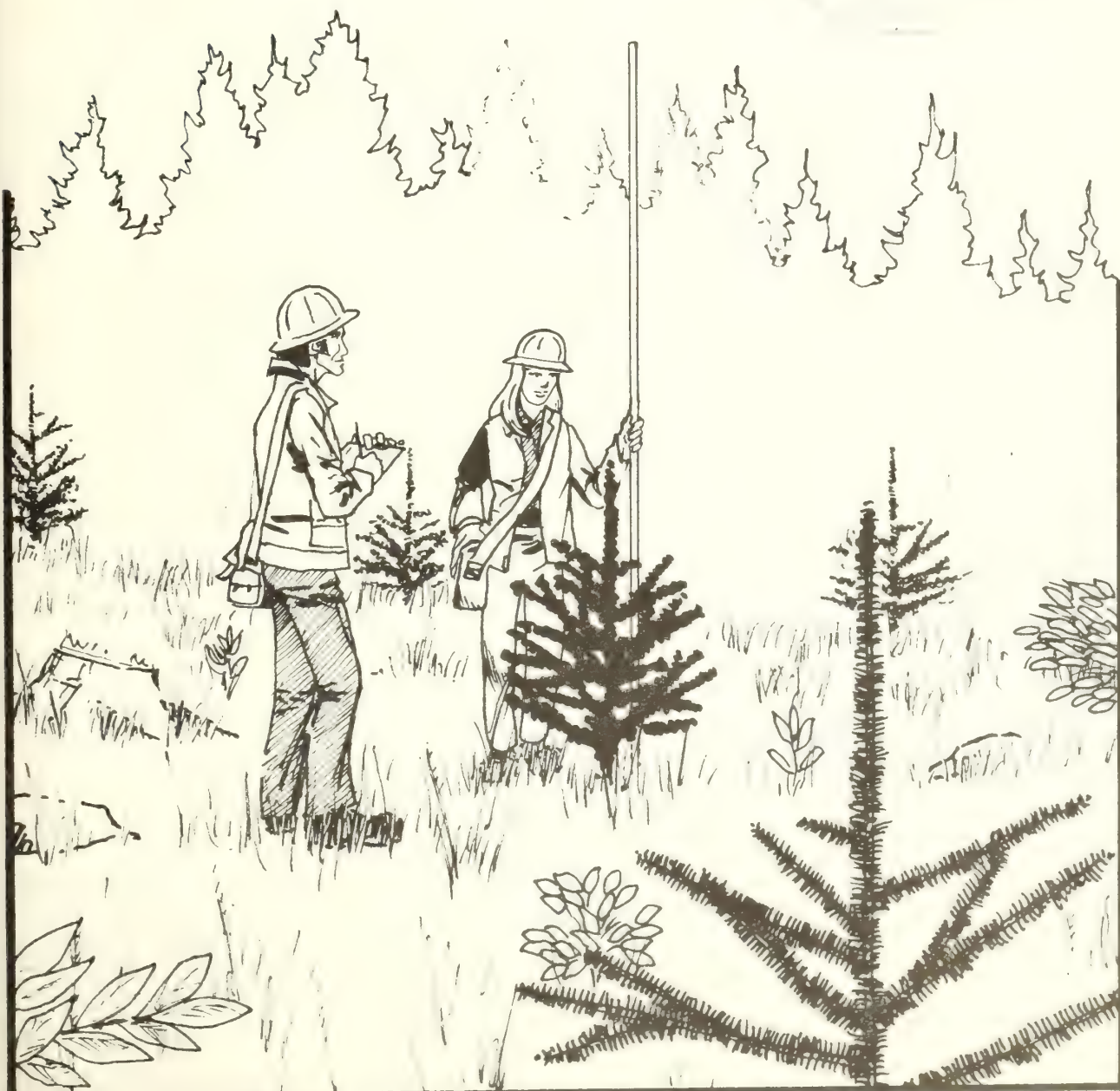
General Technical  
Report  
PNW-191

March 1986



# A Method for Assessing the Silvicultural Effects of Releasing Young Trees From Competition

Peyton W. Owston, Mel Greenup, and Valerie A. Davis





This publication describes procedures that may involve use of pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed have been registered. All uses of pesticides must be registered by appropriate State and/or Federal agencies before they can be recommended.

CAUTION: Pesticides can be injurious to humans, domestic animals, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

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## Abstract

**Owston, Peyton W.; Greenup, Mel; Davis, Valerie A.** A method for assessing the silvicultural effects of releasing young trees from competition. Gen. Tech. Rep. PNW-191. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986**. 18 p.

Systematic, long-term measurements of the survival and growth effects of releasing crop trees from competing vegetation are important for evaluating vegetation management treatments in forest plantations. This report details field-tested procedures for use in any type of release treatment—mechanical, manual, biological, or chemical. The basic concept is to delineate one untreated plot within each plantation to be monitored and to compare survival and growth on that "control" plot with survival and growth on a treated plot that is similarly delineated. Each installation should be examined periodically for a 5- to 10-year period. Sample data forms with partially completed examples are included.

**Keywords:** Vegetation management, plant competition, plantation release.

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## Introduction

Thousands of acres of forest land are treated each year to release young conifers from competing vegetation. This practice is based on the ecological principle that resources such as moisture, sunlight, and nutrients will support only a specific amount of plant growth. Competition for these resources can result in reduced survival, growth, and vigor of desired plants.

Numerous studies, as reviewed by Stewart and others (1984), support the idea that selective control of less desirable species can result in greater production of more desirable species. Unfortunately, most of this research has been for limited sets of conditions and for short periods of observations. The true benefits of crop-tree release—increased yields or higher product values—however, are not realized until the timber is harvested many years after treatment (Stewart and Row 1981). Thus, measuring the long-term growth effects of release is important to ensure that programs are achieving their silvicultural objectives and are cost effective. In addition, local data on growth impacts after treatment are also important in convincing a concerned public that sound vegetation management programs are in their best long-term interest.

The procedures described in this publication are designed primarily for land managers who wish to monitor the long-term effects of their operational treatments. It is, in essence, a quality control program to let managers know if treatments are accomplishing their objectives. Scientifically sound procedures are needed to assure the validity of results. Step-by-step procedures for selecting areas, installing plots, and gathering and summarizing data are included. The procedures are being pilot tested on the Siskiyou National Forest in southwestern Oregon for evaluating treatments applied aerially or on the ground. The plan is not designed to answer research questions and is not suitable for comparing different types of treatments.

The most efficient way to conduct such a program is to enlist the efforts of silviculturists, technicians, and scientists. Silviculturists with knowledge of management goals and local forest conditions should take prime responsibility for establishing specific objectives and for selecting plantations to be monitored; technicians trained in standard forestry field procedures can perform the plot-establishment and measurement tasks; scientists can be enlisted for general consultations and for assistance with data analysis and interpretation, and they can provide continuity to the program. Land management organizations without direct access to scientists can obtain the needed help by contracts or cooperative agreements.

Nonresearchers interested in general background information about the principles and techniques for simple administrative studies should read LeBarron (1962), Stafford (1985), and White (1984), who clearly and concisely discuss statistical topics such as replication, randomization, and design simplicity. For further, more detailed description for establishing and maintaining silvicultural plots, read Curtis (1983). Although his paper deals primarily with stands of larger trees, many of the ideas are applicable to plots in young plantations. He covers such topics as buffer strips, equipment checklists, and data management.



The basic concept of this plan is to delineate two plots in each plantation to be monitored, to include one in the operational treatment and to leave the other untreated, and to measure survival and growth of crop trees and other vegetation on the plots periodically until a consistent trend develops—usually in 5 to 10 years. Each set of two plots in a plantation is a replicate for statistical analysis. Installing three or four sets of plots in a single plantation provides more reliable data for that particular unit because more of its variability can be sampled, but that intensity of sampling is beyond the scope of a monitoring program.

## Objectives

The primary objective of the procedures to be described is to determine if plantations treated for release from plant competition have higher survival and grow faster than if they are not treated. For interpreting the survival and growth results, it must also be determined if release treatments alter the species composition or reduce the amount of noncrop vegetation (that is, decide if the treatments were effective in controlling the target species).

## Procedures Plan Development

*Determine the scope of the program.* This could vary from seeking answers for one type of site, vegetation type, plantation age, or treatment to wanting information for an entire release program of a large ownership. The scope will determine a population of plantations. Deciding which of these to monitor and how many is discussed in the next section.

*Write a specific plan for each monitoring program.* The plan should include such details as specific objectives, a list of plantations to be monitored, procedures, time schedule, estimated costs and work force needs, and how the data will be analyzed and used.

## Plantation Selection

*List all the potential plantations that define the sampling population for a given period.* This might be for 1 year or for the length of a planning cycle.

*From these, draw a random sample for monitoring.* For programs designed to answer questions for a specific type of site or treatment, four replicates (hereafter termed plantations) constitute a practical minimum for a reasonably sensitive statistical analysis. Broader objectives require more samples because variability tends to be greater on a wider range of sites and situations. At this point, consultation with a statistician is helpful.

*Spread the installations over time to lessen the work load in any one year and to sample a variety of weather conditions.* For example, if 15 plantations are considered adequate for a particular objective, establish five per year for 3 years or three per year for 5 years.

*Visit each selected plantation to confirm the feasibility of installing monitoring plots in it.* Reasons for rejection are poor stocking or terrain in which a plot could not possibly be left untreated (for example, a small unit to be aerially sprayed in which it would be physically impossible to leave a plot unsprayed). Since rejection of a randomly selected plantation would introduce a sampling bias, rejections should be made only as a last resort.

## Plot Selection and Layout

*Select two plot areas within each plantation prior to treatment.* The plots in plantations to be aerially treated should be at least 0.4 hectare (about 1 acre) in size. Plots about two-thirds that size are sufficient for units to be treated from the ground by any method. The plot areas should be relatively homogeneous internally, similar to each other, and representative of the plantation in terms of aspect, slope, soil type, and vegetation. The plots should be located away from timber edges, streamsides, fill banks, and other features that are not typical of the plantation. Terrain should be such that either plot in a plantation could be left untreated.

*Do not use buffer strips as no-treatment plots.* These areas tend to be atypical of the plantation and violate the principle of random assignment of treatments.

*Use a hand compass and chain tape to locate the boundaries of the plots.* Square plots, 60 meters (197 ft) on a side for aerial treatments and 45 meters (148 ft) per side for ground applications, are convenient, but the shape can vary as long as both plots in any plantation are the same size and shape. The plots should be kept at least 30 meters (98 ft) apart in plantations to be aerially or broadcast sprayed so that the spray does not drift to the no-treatment plot.

*Mark plot corners with steel fenceposts, reference one of them to a prominent landmark by azimuth and distance, and indicate locations on plantation maps.*

*Randomly select the no-treatment ("control") plot by flipping a coin.*

## Site Description and History

*Record information about the site that will assist in interpreting the results.* Records should include general information about the site—location, geology, soil, climate, vegetation, animal populations, aspect, slope, and other notable site features.

*Record the history of the plantation—dates and types of harvest, site preparation, planting operations, and any survey data collected.* Details of the release treatment(s) to be evaluated should be included.

## Treatment

*Mark the no-treatment plot clearly, and assign someone the task of assuring compliance with the plan.*

*Treat the plantation according to the operational plan.* The plot to be treated should be included as part of this operation.

*Use spray-deposit cards to confirm treatment patterns for aerial spray treatments.*

*If the pilot misjudges the plot boundaries somewhat but still leaves sufficient area untreated, move the plot boundaries accordingly as long as the site and conditions do not change.* In the Siskiyou National Forest trials, we have had to move boundaries by as much as 15 meters (49 ft) on several occasions.

*If the plantation becomes slated for retreatment during the study period, decide whether or not to analyze the long-term differences resulting just from the initial treatment or to keep the no-treatment plot untreated throughout the monitoring period. The latter choice seems the logical one for most situations. This will require good office records and coordination of activities.*

*Maintain uniform tree density within and around the plots at the level appropriate for your management regime (that is, thin as necessary). This will allow you to compare yields between treatments.*

#### **Selection of Trees To Be Measured**

*Establish 16 points on a grid within each plot. For square plots, a 4 by 4 grid of points at 10-meter (33-ft) intervals in the middle of the plot works well. This leaves a buffer of about 15 meters (49 ft) on all sides of the grid for 60- by 60-meter (197-ft) plots that were aerially sprayed.*

*Use a hand compass and chain tape to establish the grid, mark the grid points with cedar stakes or the equivalent, and attach a tag to each stake that identifies the point number (1 to 16).*

*Locate the three crop trees (healthy trees of desired species and spacing) nearest to each point, but do not go more than 8 meters (about 25 ft) for any tree (thus, some grid points may have fewer than three selected trees). Once a tree has been selected for one point, it should not be used for another.*

*Record the azimuth and distance from the point to each tree selected, and mark each tree with a numbered metal tag wired to a low side branch. To avoid confusion, it is best to use numbers 1-96 so that each tree selected in a plantation has its own number.*

Figure 1 is a schematic diagram of a plot installation.



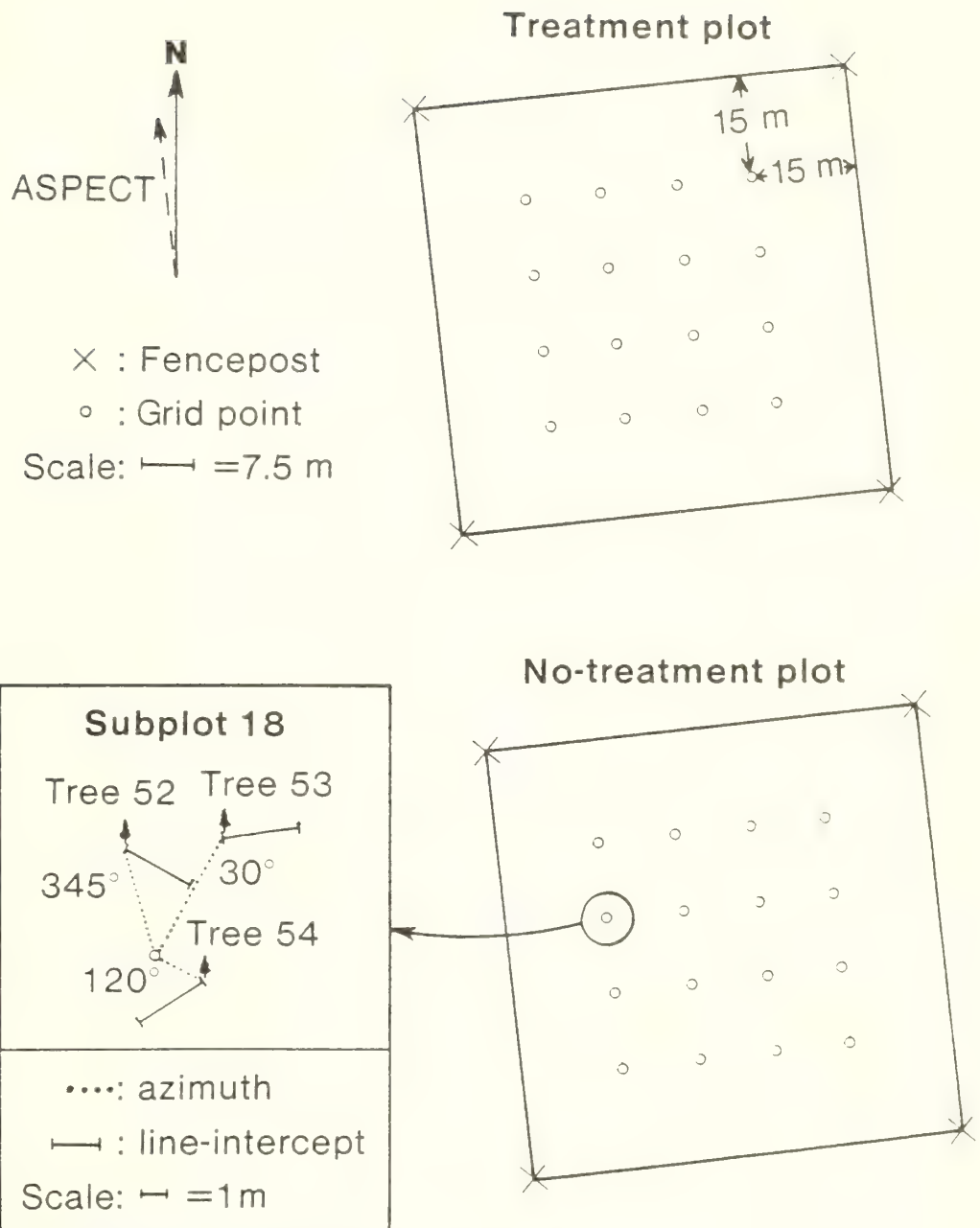


Figure 1.—Diagram of a typical plot installation. Small circles represent grid points. The detailed grid point is an example of the three sample trees and the line-intercepts for a point in either plot.

## Tree Measurements

*Measure the selected trees during the dormant season after treatment and periodically thereafter. A reasonable schedule might be 1, 3, 5, and 10 seasons after treatment (plots and trees must be marked carefully when examinations are more than 2 years apart!).*

*At the first measurement, record total height to the nearest centimeter (preferable) or inch (from ground surface at midpoint of stem to the base of the terminal bud of the main leader or branch that appears likely to become the leader), height growth during year of treatment and, where possible, for each of the two preceding years. As minimum supplemental information, each tree should be coded as having normal or damaged leaders so that separate growth analyses can be done on undamaged trees. A more complete description of condition and causes of abnormalities will yield more precise analyses. A workable coding system adapted from the Siskiyou study follows in the next section.*

*Record the competitive status of each study tree at each examination in terms of crown position relative to nearby tree and shrub vegetation using the following definitions adapted from Baker (1950): dominant—trees with crowns above the general level of the canopy; codominant—trees in the main canopy level and receiving overhead light; intermediate—crowns subordinate to those in the general canopy and receiving overhead light only from holes in the canopy; suppressed—crowns entirely in lower layers of canopy and receiving very little light.*

*Measure stem diameter to nearest 1 millimeter (preferable) or one-sixteenth inch beginning the second examination after treatment and every other examination thereafter. Measurements should be taken with a caliper at 30 centimeters (1 ft) above the ground until the tree reaches breast height. When the first measurement at breast height is taken, the diameter at 30 centimeters (1 ft) should also be recorded.*

Figure 2 is a partially completed data form organized so that it can be used for entering the data into a computer.

For additional information on the crop trees, we recommend that a stocking survey be made in each plot when the tree measurements are made. It is best to use whatever system is normally used by the organization conducting the program. For systems using circular plots, the grid points make convenient plot centers. Stein (1984) discusses fixed-plot methods for evaluating regeneration.

# Conifer Data Form

Unit name: Siskiyew National Forest Unit # 01 Treatment name: Control Treatment # 01

1st year Date 9/21/92 Recorder P. Bear 3rd year Date 10/10/94 Recorder M. Bear

Grid Pt	Tree No	Azimuth	Distance	Height			Stem diam	Flag	Injury		Height			Stem diam	Flag	Injury	
				Crp	Spring	Fall			Ldr	Stm	Crp	Spring	Fall			Ldr	Stm
1	1	144	310	1	31	44	4	HN	HN	HN	HN	HN	HN	HN	HN	HN	HN
	2	239	130	1	35	50	6	HN	BB	HN	HN	HN	HN	HN	HN	HN	HN
	3	26	200	1	27	46	6	HN	BB	HN	HN	HN	HN	HN	HN	HN	HN
2	1	180	130	3	25	30	2	YW	FB	HN	HN	HN	HN	HN	HN	HN	HN
	2	360	360	2	44	60	6	HN	FB	HN	HN	HN	HN	HN	HN	HN	HN
	3	210	210	4	40	45	3	YW	CW	HN	HN	HN	HN	HN	HN	HN	HN

Crp (crown position).

1 - dominant—crowns above the general level of the canopy.

2 - codominant—trees in the main canopy level and receiving overhead light.

3 - intermediate—crowns subordinate to those in the general canopy and receiving little overhead light.

4 - suppressed—crowns entirely in lower layers of canopy.

Flag - foliage, Ldr - terminal leader, Stm - main stem below terminal leader

Figure 2.—Conifer data form (partially completed).



**Code for Recording  
Conifer Injury<sup>1/</sup>**

**Symptoms:<sup>2/</sup>**

**Foliage condition—**

- H – Healthy
- Y – Chlorotic (yellow)
- N – Necrotic
- D – Defoliated
- B – Dead buds on lateral branches
- O – Other (specify)
- K – Specimen dead
- X – Specimen missing

**Leader condition—**

- H – Healthy
- C – Curled
- F – Forked
- B – Browsed
- D – Dieback (specify length (cm))
- T – Dead terminal bud
- S – Snapped, broken
- M – Missing
- O – Other (specify)
- K – Specimen dead
- X – Specimen missing

**Main stem condition—**

- H – Healthy
- P – Bark peeled or abraded
- B – Stem bent
- T – Stem toppled or lodged (that is, bent from base)
- S – Smashed, crushed, trampled
- C – Cut, clipped, broken
- O – Other (specify)
- K – Specimen dead
- X – Specimen missing

---

<sup>1/</sup> Adapted from Walstad, J.D.; Wagner, R.G. CRAFTS experimental design manual for B-level studies: release of young conifer stands from uniformly distributed brush competition. Unpublished study plan, April 1982, on file in the Department of Forest Science, College of Forestry, Oregon State University, Corvallis, Oregon.

<sup>2/</sup> Enter code letter in the first column of Flg, Ldr, or Stm under "Injury" for the appropriate year as shown in figure 2.

Cause:<sup>3/</sup>

- N – None
- H – Herbicide
- E – Mechanical equipment
- T – Hand tools
- S – Falling slash
- X – Falling or sliding debris
- W – Weather, environment
- R – Rodents, small animals
- B – Big game
- L – Livestock
- F – Fire
- I – Insects
- D – Disease
- V – Damage from protection device (for example, shade card or bud cap)
- O – Other (specify)
- U – Unknown

## Vegetation Assessment

*Use measurements of the shrub and herbaceous vegetation to indicate the initial and subsequent levels of competition. These measurements indicate the effect of the treatment on target species, which will aid in interpreting tree responses. The measurements should be made each time the conifers are examined. A pretreatment examination would be useful for more precise judging of treatment effects on the vegetation, but it is not mandatory.*

We use a line-intercept technique to measure noncrop vegetation because the method is relatively fast to use, provides consistent results between trained examiners, and can be analyzed quantitatively. In this method, a line of predetermined length is stretched over the vegetation, and the length of line intercepted by the canopy is measured by species or type of vegetation. We recommend the metric system, and we use a line that is 240 centimeters long. For the English system of measure, a line 100 inches long is convenient. The measurement pole is a rigid plastic pipe with a steel measuring tape attached along it with strapping tape to provide the scale. A line-intercept is established at each crop tree selected for measurement, and the main stem of the tree is used as the beginning of the line. Data are summed and expressed as a percent of the line occupied, which is roughly equivalent to percent cover.

*This optional line-intercept technique is conducted as follows: To eliminate bias, locate each line along a random azimuth (for convenience, randomly choose the azimuth from the set of 35 that fall at even 10-degree intervals). To collect the data, place the zero end of the pole at the main stem of the sample tree at a height most convenient for measuring the vegetation on that particular transect—usually on the ground. Extend the pole on or parallel to the ground at the selected azimuth. Mark the ground at the far end of the pole with a stake or pin to facilitate accurate relocation in subsequent years.*

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<sup>3/</sup> Enter code letter in the second column of Fig, Ldr, or Stm under "Injury" for the appropriate year, as shown in figure 2.

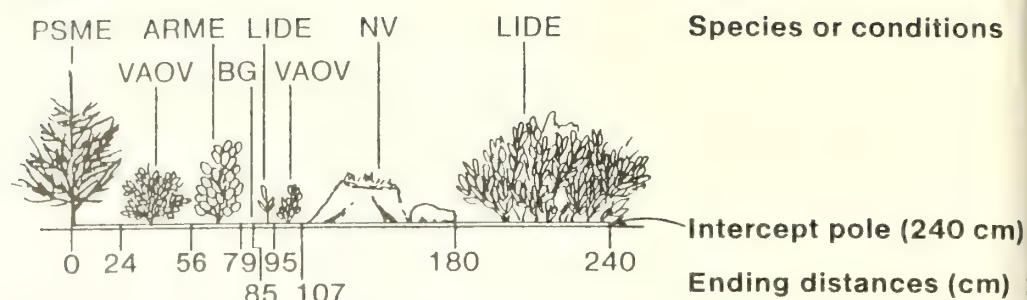


Figure 3.—Diagram of a typical line-intercept. Species and conditions depicted are: PSME—Douglas-fir seedling, VAOV—evergreen huckleberry shrub, ARME—Pacific madrone seedling, BG—bare ground, LIDE—scrub tanoak, and NV—nonvegetated area (stump, rock, etc.).

Figure 3 depicts a typical line-intercept; the numbers show end points of the measurement segments along the 240-centimeter pole.

*Record the dominant vegetation or ground condition that intercepts (crosses) the plane of the pole (that is, the pole defines an imaginary plane from the ground to the sky). The species notation system described by Garrison and others (1976) is recommended; that is, an acronym is created by using the first two letters of the genus name plus the first two letters of the species name. Thus, Douglas-fir (*Pseudotsuga menziesii*) is shown as PSME.*

*Record only species or conditions that occupy 5 centimeters (2 in) or more of the line. Distinguish and record species of woody plants, types of herbaceous vegetation, bare ground (BG), and nonvegetated areas (NV) that cannot support plant growth (stumps, logs, rocks, etc.).*

*For ease and accuracy in recording, note the ending point (centimeter or inch) of each segment. Lengths of the individual segments can be calculated later, as described under "Vegetation Assessment," p. 14).*

*For additional information, record the maximum heights of the three most dominant species of plants along each line.*

*Record injuries to the vegetation and their cause as shown under "Damage Code for Recording Brush Injury/Control."*

The line-intercept survey can be as general or as detailed as is deemed necessary by individual silviculturists. The term "dominant" is key, however—there should be only one entry for any given segment of line. For example, when there is live vegetation, the dominant species is the one that a trained observer estimates to be the most competitive for site resources. Thus, a thick, low cover might dominate over a few taller but sparse branches. When determining dominance, the plane from the ground to the sky should be considered—tall, overhanging branches should not be overlooked. Dead herbaceous plants should be included in fall examinations under the assumption that they were alive during the growing season. An estimator may want to clump several small groups of the same species into one reading to speed the procedure.

Figure 4 is a partially completed data form. Tree number 01 applies to the line-intercept illustrated in figure 3. As recorded, each data entry in the "distance" column represents the end point of each measurement segment.



# Vegetation Data Form

Unit name: Siskiyou One Recorder: S. Bear Date: 9/21/82

Unit # 01 Treatment # 2 Exam year 01

Tree #	Species	Dist	Height	Damage		Tree #	Species	Dist	Height	Damage	
				Flg	Stm					Flg	Stm
01	PSME	24		HN	HN						
	VAOV	56	80	YW	HN						
	ARME	79	25	HN	HN						
	BG	85									
	LIDE	95		HN	HN						
	VAOV	107		AH	PH						
	NV	180									
	LIDE	240	111	NH	HN						
02	PSME	26	52	HN	HN						
	PTAQ	59	57	YW	HN						
	LIDE	96		HN	HN						
	BG	217									
	LIDE	240	120	HN	HN						
03	ARCO	49	145	HN	HN						
	NV	69									
	ARCO	81	59	HN	HN						
	NV	104									
	BG	145									
	LIDE	240	88	HN	HN						

Dist = distance from zero point (tree stem), Flg = foliage, Stm = stem.

Figure 4.—Vegetation data form (partially completed). Species and conditions listed are: PSME—Douglas-fir, VAOV—evergreen huckleberry, ARME—Pacific madrone, BG—bare ground, LIDE—tanoak, NV—nonvegetated area, PTAQ—bracken fern, and ARCO—hairy manzanita.

Summation and analysis of line-intercept data are described later.

A variety of other techniques can be used for vegetation measurements. These range from visual estimates of cover density on milacre plots to detailed measurements of individual plants. Selection of the method depends on factors such as type of cover, skills and continuity of the field crew, and time available. Chambers and Brown (1983) present a good synthesis of different methods.

Growth of the crop trees is the response of most interest in this type of program, so the vegetation measurements should not be made in such detail that the monitoring program bogs down.

**Damage Code for  
Recording Brush  
Injury/Control**  
(see footnote 1, p. 8)

Symptoms:<sup>4/</sup>

Foliage condition—

- H – Healthy
- E – Enlarged leaves
- D – Deformed leaves
- R – Reduced leaf size
- Y – Chlorotic
- N – Necrotic
- A – Leaves absent (defoliated)
- B – Browsed
- O – Other (specify)
- X – Specimen absent

Stem condition—

- H – Healthy
- S – Shortened internodes
- P – Partial topkill, vigorous stem sprouting
- W – Partial topkill, weak sprouting
- T – Complete topkill, vigorous basal sprouting
- B – Complete topkill, weak basal sprouting
- D – Dead (no visible living parts)
- R – Browsed, removed
- O – Other (specify)
- X – Specimen absent

---

<sup>4/</sup> Enter code letter in the first column of Flg or Stm under "Damage," as shown in figure 4.

Cause:<sup>5/</sup>

- N – None
- H – Herbicide
- E – Mechanical equipment
- T – Hand tools
- S – Falling slash
- X – Falling or sliding debris
- W – Weather, environment
- R – Rodents, small animals
- B – Big game
- L – Livestock
- F – Fire
- I – Insects
- D – Disease
- O – Other (specify)
- U – Unknown

## Data Analysis

### Conifer Performance

*Calculate average survival percents, heights, and diameters (and the standard deviations) of the crop trees for each plot each time an examination is made. Standard statistical packages available for programmable calculators or microcomputers are recommended for this task. The differences between the treated and untreated plots on a harvest unit can then be used to assess the effectiveness of the release treatment. The differences can be calculated in terms of all crop trees, those in specific crown classes, and those in specific damage or condition classes. Plotting curves of height over age for individual units or averages of groups of units is a good visual means of seeing differences between treatments if they exist.*

*Analyze differences by standard analysis of variance procedures. Each set of two main plots (that is, the treatment and control plots in one plantation) can serve as a replicate in a randomized block experiment when two or more sets are available in a planned, representative sample of a population for which you want to make management inferences. Three sets of plots—that is, three plantations—is a practical minimum for reasonable statistical sensitivity. When the replication (plantation) =  $r$ :*

<u>Source of variation</u>	<u>df</u>
Replications	$r-1$
Treatments	1
Error	$r-1$
Total	$2r-1$

Guidelines cannot be given for judging the biologic or economic significance of the results and differences between treatments. This must be done within the context of time, place, and situation for each particular program.

---

<sup>5/</sup> Enter code letter in the second column of Flg or Stm under "Damage," as shown in figure 4.



## Vegetation Assessment

*Compare the vegetation data between treated and untreated plots to help interpret the crop tree results as well as to evaluate the effectiveness of the release treatment(s) on the target vegetation.* For example: If crop-tree response did not differ between treatment and no-treatment plots but vegetation was significantly reduced on the treated ones, the treatment may not have been necessary; if the growth of competing vegetation did not differ between plots, the treatment was probably not effective in reducing competition; if crop trees on the treated plots grew better, the treatment was probably biologically effective. Economic and environmental analyses are necessary to complete the evaluation.

*To summarize and analyze the line-intercept data, convert the "distance" or end-point numbers into segment lengths and total the lengths by the species or other categories recorded for each line-intercept.* After that, the information can be converted to percent cover, summarized by plots, and compared by treatments—including statistical analyses when treatments are replicated and randomized.

A microcomputer is useful for doing the summary. The steps enumerated below are written in a logical sequence for a computer programmer to follow in developing a program. The steps can also be followed for summarizing the data by hand:

1. The first entry in the distance column for a line-intercept equals the length of the first segment (24 centimeters in the example in figs. 3 and 4).
2. *Subtract that distance (termed "current") from the next distance to determine the length of the next segment* ( $56 - 24 = 32$  cm in the example).
3. That next distance (56 cm) becomes the current distance. *Repeat step 2 until the current distance equals 240 centimeters.* That completes one line-intercept (in the example,  $79 - 56 = 23$ ;  $85 - 79 = 6$ ;  $95 - 85 = 10$ ;  $107 - 95 = 12$ ;  $180 - 107 = 73$ ; and  $240 - 180 = 60$ ).
4. *Repeat steps 1 through 3 until all line-intercepts in a plot are summarized.*
5. *Sort lengths by species or condition categories in individual line-intercepts, and add like ones together to give total coverage per line* (in the example, Douglas-fir (*Pseudotsuga menziesii*) (PSME) = 24, evergreen huckleberry (*Vaccinium ovatum*) (VAOV) =  $23 + 12 = 35$ , bare ground = 6, tanoak (*Lithocarpus densiflorus*) (LIDE) =  $10 + 60 = 70$ , nonvegetated area (NV) = 73).
6. *Sort lengths by categories within each plot, add and count like categories to give total coverage per plot and the number of line-intercepts in which a category occurs per plot.*
7. *Sort categories in order of decreasing length to indicate relative abundance in a plot.*
8. *Calculate percent cover for each category in a plot by dividing length of the category by total line-intercept length in the plot and multiplying the quotient by 100.*

Height data collected on the line-intercepts should be averaged by species in the same way as is done for the crop tree data. Data collected on vegetation damage should be summarized by the number of occurrences of each condition per species or type per plot.

## Equipment, Supplies, and Work Force

Equipment needs:

- Hand compass
- Chain tape
- Fencepost driver
- Hand tape
- Caliper
- Rule or pole for measuring trees
- Intercept pole for measuring vegetation

Supplies:

- Steel fenceposts
- Cedar stakes
- Numbered tags
- Spray deposit cards (for aerial applications)
- Materials for marking plots (as appropriate)
- Data forms (blank forms suitable for photocopying are in the appendix)

Work force needs for installing two plots in one plantation (does not include time needed for plot selection, data analysis, and interpretation of results):

- Establishment of main plots—two people for one-half day.
- Layout of grid and selection of study trees—two people for 2 days.
- Tree and vegetation measurements—four person-days *per examination*.

## Acknowledgments

Financial support for developing this methodology was provided by the Bureau of Land Management (U.S. Department of the Interior) and the Forest Service (U.S. Department of Agriculture) under the auspices of the Southwest Oregon Forestry Intensified Research (FIR) Program. The authors also thank the silviculture staffs of the individual Ranger Districts on the Siskiyou National Forest (Pacific Northwest Region) for their support and technical assistance.

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Unit name: \_\_\_\_\_ Unit # ☐ ☐ Treatment name: \_\_\_\_\_ Treatment # ☐

\_\_\_\_\_ year: \_\_\_\_\_ Date \_\_\_\_\_ Recorder \_\_\_\_\_

Grid Pt.	Tree No.	Azimuth	Distance	Height			Stem diam	Flag	Injury Ldr	Injury Stm
				Crp	Spring	Fall				
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
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<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Crp (crown position):

- 1 = dominant — crowns above the general level of the canopy;
- 2 = codominant — trees in the main canopy level and receiving overhead light;
- 3 = intermediate — crowns subordinate to those in the general canopy and receiving little overhead light;
- 4 = suppressed — crowns entirely in lower layers of canopy.

Flag = foliage, Ldr = terminal leader, Stm = main stem below terminal leader

## Vegetation Data Form

Unit name: \_\_\_\_\_ Recorder: \_\_\_\_\_ Date: \_\_\_\_\_

Unit # 

--	--

Treatment # Exam year  [illegible]

Dist = distance from zero point (tree stem), Flg = foliage, Stm = stem.

**Owston, Peyton W.; Greenup, Mel; Davis, Valerie A.** A method for assessing the silvicultural effects of releasing young trees from competition. Gen. Tech. Rep. PNW-191. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986**. 18 p.

Systematic, long-term measurements of the survival and growth effects of releasing crop trees from competing vegetation are important for evaluating vegetation management treatments in forest plantations. This report details field-tested procedures for use in any type of release treatment—mechanical, manual, biological, or chemical. The basic concept is to delineate one untreated plot within each plantation to be monitored and to compare survival and growth on that "control" plot with survival and growth on a treated plot that is similarly delineated. Each installation should be examined periodically for a 5- to 10-year period. Sample data forms with partially completed examples are included.

**Keywords:** Vegetation management, plant competition, plantation release.

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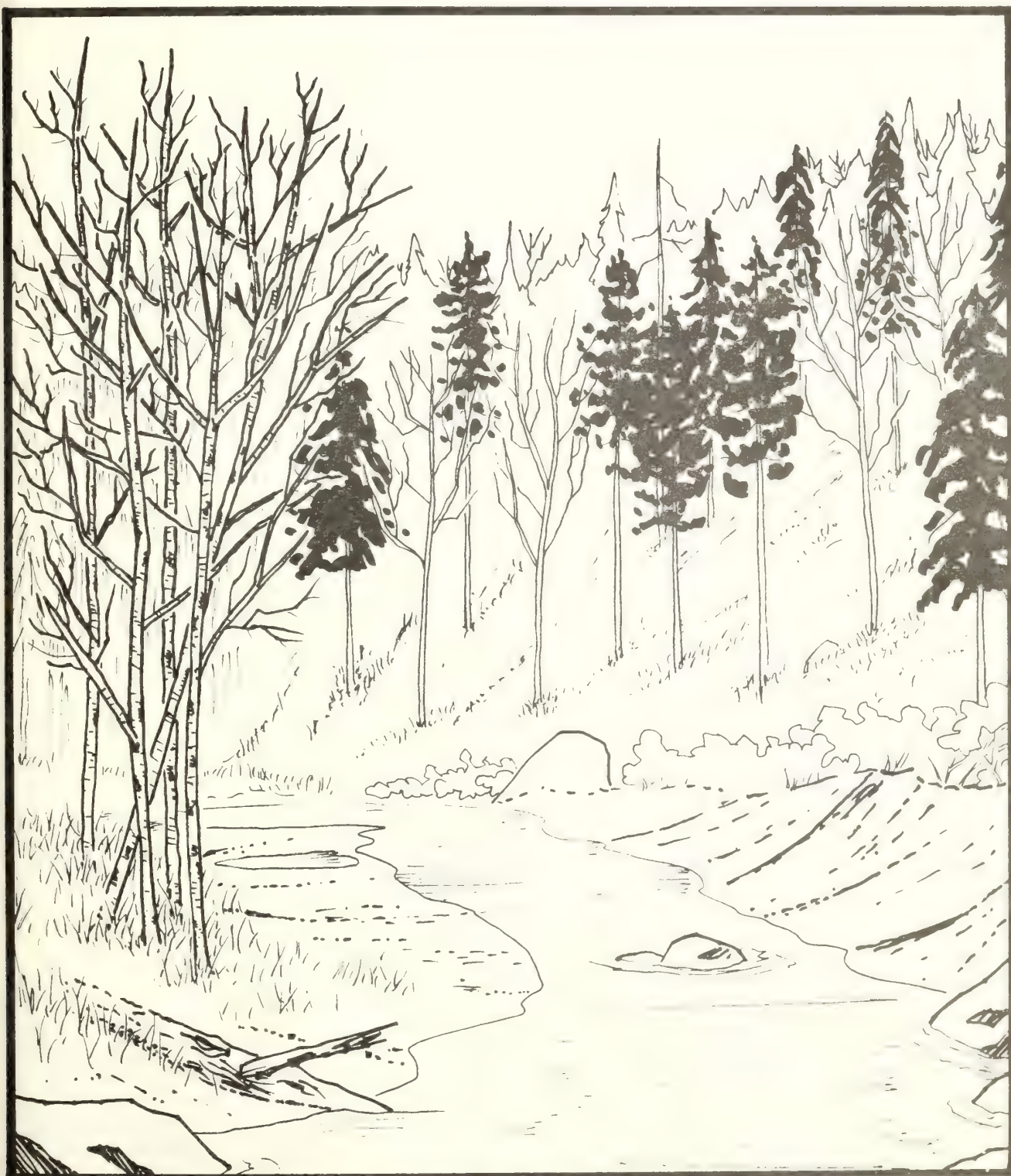
Forest Service

Pacific Northwest  
Research Station

General Technical  
Report  
PNW-192  
March 1986

# A Method of Site Quality Evaluation for Red Alder

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## Abstract

**Harrington, Constance A.** A method of site quality evaluation for red alder. Gen. Tech. Rep. PNW-192. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986**. 22 p.

A field guide to predict site index for red alder (*Alnus rubra* Bong.) was developed for use in western Washington and Oregon. The guide requires the user to evaluate 14 soil-site properties that are grouped into three general factors: (1) geographic and topographic position, (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition. Construction of the guide was modeled after a method of site evaluation developed for several southern hardwood species. The red alder model is accurate when used properly. The correlation ( $r$ ) between predicted and measured site index was 0.97 for the basic data set of 25 plots and 0.96 for the 15 plots used for verification. Estimated site index should be within  $\pm 2$  meters of measured site index 95 percent of the time. Use of a second independent data set for model verification resulted in a somewhat lower correlation ( $r = 0.89$ ) between measured and predicted site index than was achieved with the original data set, but the model continued to meet the accuracy standard of  $\pm 2$  meters ( $p \leq 0.05$ ).

**Keywords:** Site class, site index, guidebooks, models, red alder, *Alnus rubra*.



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## Introduction

Forest managers need site-specific information on site quality to make intelligent decisions regarding species selection and management practices. The most commonly used measure of potential site productivity is site index (mean height of upper crown class trees that have been free to grow in an even-aged stand at a specified index age). It is, however, difficult or impossible to accurately assess site index in stands that are uneven aged, mixed species, very young or very old, or on sites where the species of interest is not growing.

Several methods have been developed for predicting site quality for a species when it cannot be directly measured (Mader 1965). The most common methods use: (1) measured soil and site characteristics in a mathematical equation, (2) soil mapping units, or (3) the presence or growth of other plant species. Prediction of site index by use of soil and topographic characteristics in a multiple regression equation (method 1) was popular in the United States from the 1930's through the 1960's; Coile (1952), Ralston (1964), Berglund (1968), and Carmean (1975) provide good reviews of the subject. These studies were useful in identifying the soil and site characteristics correlated with site index. In most studies the selection of variables for the final regression equation was based on mathematical relationships. Composite or transformed variables, as well as simple variables, were often utilized. Many of these mathematical soil-site studies resulted in final prediction equations with high multiple correlation coefficients. The biological interpretation of the resulting complex equations was often difficult, however, and the applicability of the equations was usually limited to small uniform areas. In addition, equations that accounted for the majority of observed variations in site quality could not always be developed. This type of classical soil-site study has been criticized for both mathematical and biological reasons (Broadfoot 1969, Hodgkins 1959, Lloyd and Lemmon 1970) and is currently used much less commonly than in the past. Use of existing soil mapping units or other plant species has been helpful in distinguishing between broad classes of productivity; however, in most cases these approaches have not yielded the desired precision for estimating site quality (Harding and Baker 1983, Mader 1965, Youngberg and Scholz 1949).

In 1977, Baker and Broadfoot of the Southern Forest Experiment Station published a new method of site quality evaluation that combined both subjective and objective approaches. They first evaluated the relative importance of four major soil factors on growth of a particular species. The soil factors were: (1) physical condition, (2) moisture availability during the growing season, (3) nutrient availability, and (4) aeration. Next, they identified (and later quantified) the specific soil-site properties that best described or summarized the effect of each soil factor. They then developed field guides that could be used in evaluating site quality for 14 southern hardwood species; verification with field data indicated high accuracy over a broad range of sites (Baker and Broadfoot 1977, 1979).

This paper presents a set of site evaluation tables for predicting site index for red alder (*Alnus rubra* Bong.) The tables contain 14 soil and site properties organized into three major factors: (1) geographic and topographic position, (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition. The red alder model was patterned after Baker and Broadfoot's (1977, 1979) approach; that is, the basic framework was subjectively derived based on an understanding of the site requirements of the species. The model was developed and tested with data from 40 natural stands located over a range of site conditions in western Washington and Oregon.



## Field and Laboratory Methods

Forty natural, even-aged, well-stocked red alder stands in western Washington and northwestern Oregon were selected for sampling (fig. 1). Stand ages ranged from 25 to 50 years; mean age of all stands was 36 years. A deliberate attempt was made to sample a wide range of soil conditions and of productivity (table 1). All sampled stands were pure red alder, or when mixed, the other species were not in a crown position to have suppressed past alder height growth. Within each selected stand one 0.10-ha plot was established. Plot boundaries were kept away from roads and did not cross any obvious stand boundaries or changes in stand or site conditions. When soil and stand conditions were fairly uniform, plots were square (31.6 m on each side). Plots along streams or on terraces were rectangular, the long axis of the plot paralleling the stream or the long axis of the terrace. Rectangular plots were 50 x 20 m.

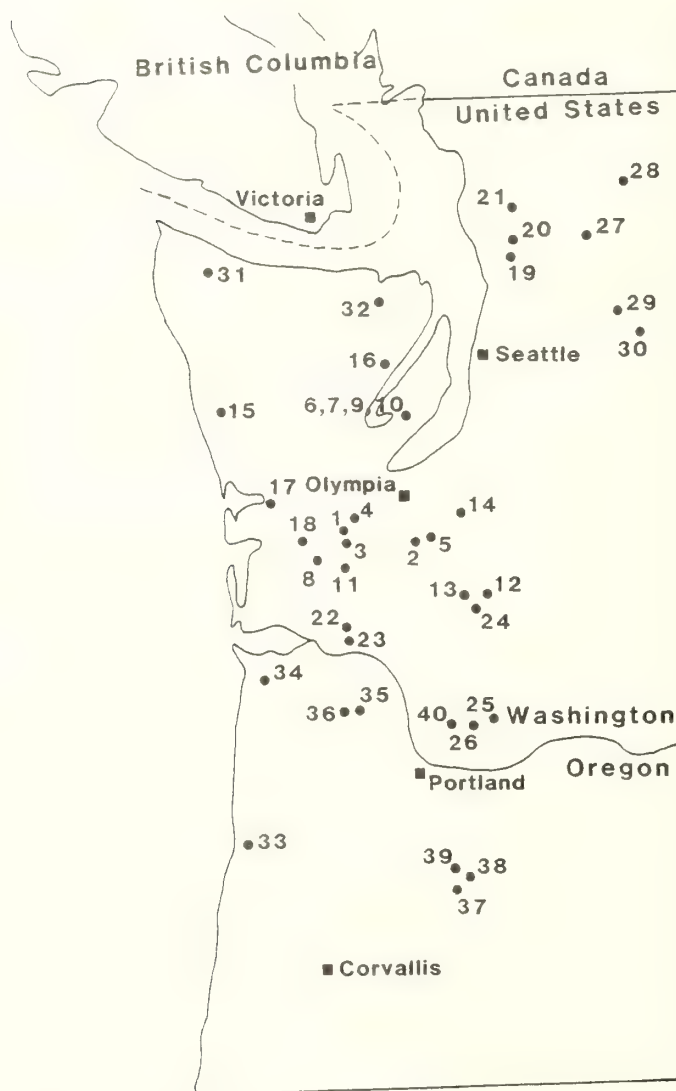


Figure 1.—Location of stands used in red alder site evaluation study.

**Table 1—Summary of selected site characteristics on plots taken in red alder stands in western Washington and Oregon**

Characteristics	Unit	Range	Mean
SI <sub>50</sub>	Meters	21.0 - 38.5	28.6
Elevation	Meters	5 - 1025	242
Slope	Percent	0 - 40	13
Soil Conservation Service drainage classes	—	2 - 7	4
Surface soil (0-10 cm):			
Clay	Percent	1 - 49	24
Sand	Percent	1 - 85	33
Organic matter	Percent	.5 - 77.4	14.5
pH	—	4.2 - 6.3	4.9

On each plot, 10 dominant or codominant trees were selected to be measured for site index. Selected trees appeared healthy and free from past top damage. Trees were bored with an increment borer to determine age at breast height; total height was measured with a telescopic abney. Site index (50-year base) was calculated from the equation of Worthington and others (1960).

Physiographic data recorded for each plot included aspect, slope percent, and physiographic position. Depth to water table during the growing season was estimated for sites along rivers and streams and for areas with poor drainage. Associated major and minor vegetation was also recorded along with comments on past history of the site (for example, evidence of burning, logging, or flooding).

In each plot at least two soil pits were dug, and their soil profiles were described. Pits were located on what appeared to be representative microsites; rotting logs, old skid trails, or other nontypical conditions were avoided. Pits were dug to a depth of 1 m or to an impermeable layer, whichever came first. Pit descriptions included depth, structure, texture, color, and coarse fragment content of each horizon. Presence of charcoal or organic debris, and extent of rooting were also noted by horizon. If the two pits on a plot differed in number, type, or texture of the horizons, a third pit was dug and described. All horizons 4 cm or thicker were sampled for bulk density. Soil volume for bulk density samples was determined in the field by use of a water-filled graduated cylinder with a rubber balloon and valve system (Blake 1965); soil weights were determined in the laboratory after samples were dried at 105 °C to constant weight. Bulk density samples were sieved for gravel and rock (>2 mm in diameter); the coarse fragments were weighed and their volume was determined by water displacement. Bulk density was calculated from both nonsieved and rock-free bases.

Two sampling transects were established in each plot. The transects were spaced to divide the plot into equal thirds. Ten sampling points were located on each transect so that there was an equal distance between the sampling points on the line and between the end points and the plot boundary. Sampling points were adjusted as necessary to avoid stumps, large rocks, or other obstacles. At each spot, samples of the forest floor and of mineral soil at 0 to 10 cm, 10 to 30 cm, and 30 to 50 cm were collected. Forest floor samples were collected with a circular template (13 cm in diameter). Heavy-gauge stainless steel tubes (7.5 cm in diameter) were used to extract the mineral horizons on most plots. Some plots were very rocky, however, and sampling spots had to be dug out with trowels and shovels. Soil samples were bulked by sampling layer, brought back to the laboratory, and air dried.

After the soil samples were air dried they were sieved and separated into soil (<2 mm in diameter), small gravel (2 to 8 mm), and large gravel (>8 mm). Each size component was weighed. The soil was then mixed well, and representative subsamples were extracted for determination of selected chemical and physical characteristics. Soil chemical characteristics were determined by the Cooperative Chemical Analytical Laboratory, Corvallis, Oregon, using the following procedures: total Kjeldahl nitrogen (Jackson 1958); Bray #1 extractable phosphorus (Jackson 1958); Walkely-Black organic carbon (Allison 1965); ammonium acetate cation exchange capacity (Jackson 1958); and exchangeable K, Ca, Mg, and Fe by ammonium acetate extraction, atomic absorption spectrophotometry (North Central Regional Soil Testing Committee 1980). Soil texture and pH were determined at the Forestry Sciences Laboratory, Olympia, Washington. Soil texture was determined by the hydrometer method of mechanical analysis (Bouyoucos 1962) with sodium hexametaphosphate as the dispersing agent; all samples were treated with 30 percent  $H_2O_2$  to remove organic matter before particle size analysis. The determination of pH was made with a standard glass electrode on a 1:1 (v/v) mixture of distilled water and soil (USDA Soil Conservation Service 1972). A subsample of the forest floor from each site was dried at 105 °C to constant weight, and the oven-dry equivalent weight of the total sample was determined.

Soil series or mapping unit was determined for each plot by comparing mapped information from USDA Soil Conservation Service, Washington State Department of Natural Resources, USDA Forest Service, or private timber companies, with descriptions obtained in the field. Appropriate local personnel were contracted for assistance when profile descriptions of the soil mapping unit did not match the descriptions obtained in the field. Rainfall from April 1 through September 30 and number of frost-free days were taken from isohyetal maps (Dick 1955). Plot elevations were determined from topographical maps.

## Model Construction

Construction of a model to predict red alder site index was accomplished in stages. First, a very general theoretical model, which listed the soil and climatic characteristics that could influence tree growth, was developed. This first model had five major components—soil physical condition, moisture availability during the growing season, soil fertility, soil aeration, and climatic characteristics.



The second step was to plot the relationships between site index and each of the measured variables. The graphs were visually examined, with particular attention given to the maximum values of site index that occurred over the range of values for the independent variable being examined. In addition, a rough tabulation was made for each property of: (1) the known variation in values throughout the natural range of the species and (2) the variation sampled in this study.

The next step in model construction was data analysis for the primary purpose of hypothesis generation. Standard statistical programs (Dixon 1981, Hull and Nie 1981) were used to perform the following analyses:

1. Simple correlation analysis (all possible combinations).
2. Stepwise discriminant analysis of three groups based on low, medium, and high site index.
3. Cluster analysis of the soil and site variables measured and of the individual locations.

The next stages in model construction required determination of the variables most closely related to site index, and for each of these variables determination of the levels associated with high and low site index. Twenty-five of the plots were randomly selected and used as a reference data set to aid in assigning quantitative values to selected variables or site characteristics. The characteristics used in this stage of model development had to meet the following criteria: (1) were theoretically important in modeling growth, (2) had substantial range in observed characteristics (at least  $\pm 20$  percent of the mean), (3) had differences in the levels of the characteristic associated with good and poor site index, and (4) were independent of (that is, poorly correlated with) other selected variables. One of the goals of this project was to provide a field guide for site evaluation that could be used by practicing foresters. Thus, when possible without reducing the accuracy of the model, the soil-site properties selected for inclusion in the model were those that could be determined with a minimum of special equipment.

The variable selection process can be illustrated by describing the steps involved in the selection of elevation, the variable with the most weight in the final model. The first theoretical model did not include elevation; it did, however, include several variables closely correlated with elevation such as length of the growing season and growing season temperatures. Generally a variable such as length of the growing season would be preferred over elevation because it more directly measures a property important to tree growth. Because of the varied and rugged topography in the region, however, many more climatic recording stations than currently exist would be necessary to provide good estimates of climatic variables. Thus, the imprecision associated with available estimates of climatic variables negated the theoretical value of having a variable that influenced growth in a direct manner. For research purposes it would be possible to estimate climatic variables from information on elevation and geographic location. This type of calculation did not seem to be warranted as it was unlikely that calculation would increase the accuracy of the relationship. In addition, users of the guide would find it easier to determine elevation than to calculate such variables as number of days in the growing season.

Elevation was highly correlated with site index and was the first variable used in the stepwise discriminant analysis; that is, of the measured variables, elevation was the most effective in separating poor, medium, and good sites. Red alder naturally occurs over a wide range of elevations, and this study sampled sites over much of the range. Thus, elevation was selected as the first variable for the model. Then, because of its high correlation with site index, elevation was determined to have a high weight in the model. Based on graphical analyses, the relationship between site index and elevation was determined to be linear. A line was drawn to correspond to the maximum values of site index (this technique is sometimes called boundary line analysis). The change in site index along this line corresponding to the maximum possible range in elevation was taken as a guide to the maximum number of site points that elevation could account for in the model. Because elevation was correlated with other variables used in the model, however, the whole range in site points observed in this two-variable relationship was not used in the final model.

Selection of the other variables to be included in the model and a preliminary determination of the maximum range in site points associated with each variable followed the same general procedure outlined for elevation.

Once the first set of variables had been selected and quantitative values were assigned, model refinement was basically an iterative procedure. The current version of the model was used to predict site index for the 25 reference plots. Soil-site properties on plots where the difference between predicted and measured site index was large were compared with soil-site properties on plots where the difference was small. This comparison facilitated the identification of the properties or levels of properties that appeared to be associated with poor model performance. Based on this information, the model was changed. The adjusted version of the model was then used to repredict site index for the 25 plots. Model adjustment involved primarily changing the values assigned to the levels of specific properties; however, two additional variables—bulk density and pH—were later added to the group originally selected.

Site conditions considered unsuitable for the species or the minimum and maximum levels for a specific soil-site property were sometimes determined from sources other than the plot data collected for the study. These other information sources included published reports on the silvics of the species (for example, Worthington and others 1962); personal communication with foresters, ecologists, and researchers familiar with the species; and personal observation.

The final model contains 14 soil-site properties divided into three general factors: (1) geographic and topographic position (which includes climatic properties), (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition. The site evaluation tables developed from the model are given in tables 2, 3, and 4.

**Table 2—Red alder site evaluation guide: factor 1, geographic and topographic position**

Soil-site property	Level of property	Site points for each level
Elevation	Less than 100 m	8
	200 - 300 m	7
	400 - 500 m	6
	600 - 700 m	5
	800 - 900 m	4
	1000 - 1100 m	3
	Greater than 1200 m	Unsuitable
Physiographic position	Flood plain	5
	Terrace or bench (includes lower slope positions with slope $\leq 20$ percent)	4
	Lower slope positions with slope $> 20$ percent and midslope positions	3
	Depression in landscape, bog, or marsh	2
	Upper slope positions	1
	Ridgetop	0
Aspect and slope	Any aspect when slope 5 percent or less	4
	E or W with slope 10-20 percent; <u>or</u> N, NE, or NW with slope 10-30 percent	3
	S, SE, or SW with slope 10-20 percent; <u>or</u> E or W with slope 25-35 percent; <u>or</u> N, NE, or NW with slope 35-45 percent	2
	S, SE, or SW with slope 25-35 percent; <u>or</u> E or W with slope 40-50 percent; <u>or</u> N, NE, or NW with slope 50-60 percent (Subtract 1/2 for each additional 10-percent increase in slope)	1
Precipitation from April 1 through Sept. 30	Greater than 45 cm	3
	30 - 40 cm	2
	20 - 25 cm	1
	Less than 15 cm	0
Special hazards	None	0
	Frost pocket	-2
	Exposed windy site	-3

Maximum score for factor 1 = 20.



**Table 3—Red alder site evaluation guide: factor 2, soil moisture and aeration during the growing season**

Soil-site property	Level of property	Site points for each level
Internal drainage	Soil generally well drained <u>and</u> composed of many thin alluvial layers (stratified)	4
	Soil generally well drained <u>and</u> profile contains buried horizons or soil lenses within a horizon that differ in texture from the surrounding horizon, or A and B horizons that differ in sand content by more than 10 percent; <u>or</u> soil moderately well drained	3
	Well drained (without special features); <u>or</u> generally somewhat excessively drained <u>with</u> multiple thin alluvial layers, buried horizons, soil lenses within a horizon that differ in texture from the surrounding horizon or A and B horizons that differ in sand content by more than 10 percent	2
	Somewhat excessively drained (without special features); <u>or</u> somewhat poorly drained	1
	Poorly drained mineral soil; <u>or</u> very poorly drained mineral soil with organic surface layers; <u>or</u> excessively drained mineral soil	0
	Very poorly drained	Unsuitable

**Table 3—Red alder site evaluation guide: factor 2, soil moisture and aeration during the growing season (continued)**

Soil-site property	Level of property	Site points for each level
Texture	Silt loam, silty clay loam, or loam with at least 40 percent silt	3
	Clay, clay loam, silty clay, or loam with less than 40 percent silt	2
	Sandy clay, sandy clay loam, or sandy loam	1
	Sand or loamy sand	0
Soil depth	Greater than 80 cm without cemented or compacted layers	2
	Between 40 and 75 cm without cemented or compacted layers	1
	Less than 35 cm or deeper soils with cemented or compacted layers within 35 cm of the surface	0
Rock and gravel content (in surface 50 cm)	0 - 25 percent (by weight)	1
	30 - 50 percent	0
	More than 55 percent	-2
Depth to water table (in summer)	1.8 - 3 m	2
	1 - 1.5 m or greater than 4 m	1
	Less than 0.75 m	0

Maximum score for factor 2 = 12.

**Table 4—Red alder site evaluation guide: factor 3, soil fertility and physical condition**

Soil-site property	Level of property	Site points for each level
Parent material	Young soils composed of water-carried silt deposits; presence of soil layers caused by water deposition not weathering	4
	Some profile development evident but no leached horizons; parent material sedimentary or volcanic rocks (especially soils with low coarse fragment content developed from siltstone, sandstone, shale, or basalt); includes loessial soils if deposits are thick	3
	Some profile development evident but no leached horizons; parent material coarse alluvial, glacial or volcanic deposits (or soils with high coarse fragment content developed from sedimentary or volcanic rocks)	2
	Highly weathered mineral soils with evidence of leaching; <u>or</u> organic soils	1
pH (in surface horizon)	4.6 - 5.5	2
	3.8 - 4.3 or 5.8 - 7.5	1
	3.2 - 3.5	0
	Less than 3.0 or greater than 8.5	Probably unsuitable
Organic matter (in surface 10 cm)	5 to 20 percent	2
	Less than 3 or greater than 25 percent	1
Bulk density	Less than 1.2 g/cm <sup>3</sup>	0
	1.4 g/cm <sup>3</sup> or greater	-2

Maximum score for factor 3 = 8.



Most of the measured soil chemical characteristics were not used in the final model. There are several possible reasons for this. First, soil chemical characteristics may have been correlated with more general soil properties that were included in the model. For example, percent organic matter was used in the model with both high and low levels considered suboptimal. High organic matter content was associated with poorly drained soils and with high elevation sites; in both these situations the high organic matter content probably indicates that mineral cycling rates on these sites are low. Cation exchange capacity is another soil property that theoretically would influence tree nutrition and could have appeared in the model. On these sites, however, cation exchange capacity and organic matter content were highly correlated ( $r = 0.97$ ); thus, very little additional information would have been gained by including cation exchange capacity in addition to organic matter content. Second, some differences between soils in chemical characteristics would be accounted for by the categories "Parent material and age" and "pH." Finally, the majority of forest soils in the Pacific Northwest are considered geologically young and relatively unweathered; thus, mineral deficiencies other than nitrogen may not be common. Because red alder has root nodules capable of fixing atmospheric nitrogen, it is not sensitive to soil nitrogen levels.

## Model Validation

The red alder site evaluation model fit the original data well. The correlation between predicted and measured site index was 0.97 for the 25 plots used to quantify the model and 0.96 for the 15 plots used for verification. For the original combined data set, the model accounted for 93 percent of the observed variation in site quality. Freese's (1960) chi-square test of accuracy indicated that true site index should be within  $\pm 2$  m of the predicted value 95 percent of the time.

While I was conducting this study, a similar study—with the same purpose of evaluating site quality for red alder—was being independently conducted by another researcher.<sup>1/</sup> The Crown Zellerbach study was conducted in a smaller geographic area than my study area but it sampled sites with approximately the same mean site index (27.6 m vs. 28.6 m) and covered a similar range in values for many of the soil-site properties. For example, the sites in my study had a range in elevation from 5 to 1025 m, the Crown Zellerbach plots from 5 to 950 m. Although the two studies collected information on many of the same variables, different field and laboratory methods were used. In addition, some variables (for example, bulk density) were measured in one study but not in the other. In spite of these differences in measurements and methodology, the data from this second study provided a unique opportunity to further test the red alder soil-site (RASS) model.

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<sup>1/</sup> Walter J. Shields, Research Forester, Crown Zellerbach, Wilsonville, Oregon.

Plots from the Crown Zellerbach study were used if they met the following criteria: mean tree age greater than 25 years, within plot range in tree age less than or equal to 5 years, and range in site index between trees less than 2 m. Adhering to these criteria helped eliminate trees with irregular height growth and reduced within-plot variation in site index. Plots were deleted if they had missing values for variables that could not be estimated from other plot information. Other missing or unmeasured variable values were estimated when possible. For example, bulk density was roughly estimated from the moist consistence category assigned to each soil horizon. The RASS model was then used to predict site index for 20 of the Crown Zellerbach plots. The model performed well in the test. The correlation ( $r$ ) between measured and predicted site index was 0.89. In addition, the model continued to meet the accuracy standard of  $\pm 2$  m ( $p \leq 0.05$ ).

## Use of the Site Evaluation Tables

The use of the site evaluation tables (table 2, 3, and 4) is straightforward and fairly simple. To evaluate potential site index of an area requires determination of several characteristics of the actual location or position of the site, and of various soil properties. Site points are assigned to different levels of each property. Potential site index is predicted by summing the appropriate site points for all properties. Definitions of the terms used in the site evaluation tables are given in appendix 1.

The red alder model differs from the models developed by Baker and Broadfoot (1977, 1979) in two major respects. First, it places considerable importance on the actual location or position of the site to be evaluated. Working on the southern Atlantic Coastal Plain where climate and topography are relatively uniform, Baker and Broadfoot did not include properties such as elevation, percent slope, aspect, or climatic characteristics; such properties are included in the red alder model. Second, the Baker and Broadfoot models were designed to evaluate each factor independently; this required site characteristics or properties that influenced more than one factor to reoccur in different places in the model. The red alder model evaluates each property only once; thus, the factors are additive rather than independent. For example, factor 2 for red alder (soil moisture and aeration during the growing season) can have a maximum value of 12 points. This should *not* be interpreted as implying that soil or site characteristics that influence soil moisture and aeration only explain or influence about 30 percent (that is, 12 of 40 site points) of the variation in site quality for red alder. The interpretation should be that the characteristics in factor 2 of the red alder model account for or explain an additional 30 percent of the variation not accounted for in factor 1 (geographic and topographic position), but some soil-site properties in factors 1 and 3 also influence soil moisture and aeration. Similarly, the soil-site properties in red alder factor 3 (soil fertility and physical condition) represent the site characteristics that influence soil fertility and physical condition in addition to the properties considered in factors 1 and 2.

The site evaluation tables for red alder have been set up to predict a maximum value of 40 (site index in meters at 50 years). Factor 1 at its maximum level can account for 20 site points or half the maximum total number of points. The site characteristics in factor 1 can be easily and quickly determined in the field or by using readily available information sources such as topographic maps or weather records. Thus, if a user thinks it desirable to do so, a preliminary rating of sites can be done without determination of soil properties. This preliminary rating may not be correlated with the final or total rating; however, it will indicate the maximum score the site could receive if all the soil characteristics in factors 2 and 3 are at optimum levels. For example, if a site receives 8 points in factor 1 (or a maximum of 20), then the maximum total rating the site could achieve is 28. If a user only wishes to consider planting or managing the species on sites with site index values of 30 m or more, then this site can be deleted from consideration without the necessity of examining the soil.

The site evaluation tables were deliberately designed to require the user to interpolate between site points for many properties. For example, a site at an elevation of 150 m would fall between the categories "Less than 100 m" (worth 8 points) and "200 to 300 m" (worth 7 points). In this case a value of 7.5 points would be reasonable. Similarly, a soil profile with horizons of different textures should receive an interpolated value if the individual textures are associated with different numbers of site points.

If a particular piece of information is not known or is not known very precisely, users should consider using their "best guess." Which properties have the greatest spread in point values and thus the largest impact on determination of site quality can be determined from an examination of the site evaluation tables. The properties with the greatest influence should be determined or measured accurately. "Best guess" determinations can be based on a knowledge of the most common value or range of a soil or site property. For example, if detailed weather information is not available, precipitation during the growing season is probably in the 30- to 40-cm range unless the area being evaluated is in a rain shadow, along the Pacific Coast, or in a geographic location where orographic precipitation is likely to be significant. For users who are not familiar with estimating various soil properties, spending some time in the field with a soil scientist should be very beneficial for increasing the accuracy of their determinations.

A final word of caution. Users should try to evaluate each property as objectively as possible. If before using the site evaluation tables, the user has "decided" or "knows" that the site is poor, there may be a tendency for subjective decisions to have a negative bias and thus for actual site quality to be underestimated. The reverse is also true. When evaluating a "good" site, users may tend to be overly generous in assigning site points and may overestimate site quality.

Two examples of the use of the site evaluation tables are given below. Appendix 2 contains a sample field worksheet.



Area A to be evaluated is on a northeast-facing slope of 20 percent. Elevation is 45 m and average precipitation during the growing season is 31 cm. The location is inland (near Olympia, Washington) in a midslope position and does not appear to be subject to any special hazards. The soil is a gravely to very gravely loam in the surface 35 cm a gravely sandy loam from 35 to 95 cm (a clay pan encountered at 95 cm). Silt content is 25 percent, gravel and rock content is 50 to 70 percent by weight, and the soil is well drained to somewhat excessively drained. The water table is deep, probably at 6 to 8 m. The soil formed from coarse glacial outwash material. Horizons are easily distinguished, but there is no evidence of a leached horizon (A2). In the surface 10 cm, pH is 5.0 and organic matter content is 4.0 percent. No compaction is evident in the surface 50 cm; bulk density in B2 (rock-free basis) is  $0.9 \text{ g/cm}^3$ .

Factor 1 is easily evaluated for area A (table 5). All the information fits within the specified ranges in site characteristics. Evaluation of some properties in factor 2 requires the user to interpolate. The soil was described as well drained to somewhat excessively drained and was given a rating of 1.5 (that is, halfway between the 1 rating for somewhat excessively drained and the 2 value for well drained without special features). Texture was rated as 1.75 percent. In the surface 35 cm the soil was loam with less than 40 percent silt, which would earn a rating of 2; however, since the texture from 35 to 50 cm was sandy loam, the texture rating for the surface 50 cm was reduced. The observed range in rock and gravel content crossed the level given in the table so the intermediate value of -1 was selected. Determination of the values associated with other properties in factors 2 and 3 was straightforward as no interpolation was necessary.

Summing each factor for area A gives individual factor values of 16, 5.25, and 6 for a total site rating or site index of 27.25 m. Rounding to the nearest meter results in an estimate of 27 m. A quick check of the values assigned to each factor with the total points possible indicates that area A received 80 percent of the maximum for factor 1, 44 percent of the maximum for factor 2, and 75 percent of the maximum for factor 3. Thus, we can conclude: Area A is located in a relatively favorable position in terms of geography and topography (factor 1); moisture availability during the growing season probably plays a major role in limiting growth (factor 2); and the characteristics rated for soil fertility and physical condition (factor 3) had less than optimum but not markedly unfavorable values.

Area B is located on a gently rolling bench southeast of Mount Vernon, Washington, at an elevation of 120 m. Slope averages 7 percent, and the aspect is southeast. The area receives 30 cm of rainfall April 1 through September 30. No special hazards are apparent. The soil is 75-80 cm of loam (silt content 45-50 percent) over slightly weathered sandstone and siltstone. The soil has a rock and gravel content of 10 to 15 percent and is well drained but with downward water movement slowed by the presence of the parent material close to the soil surface. Depth to a true water table is not known, but it is greater than 4 m. In the surface 10 cm, pH is 4.9 and organic matter averages 7.0 percent. Soil is friable to firm; rock-free bulk density in the B2 averages  $1.1 \text{ g/cm}^3$ .

The site evaluation of area B is given in table 6. Two properties required interpolation. Elevation was given a 7.75 rating, as it was closer to the "Less than 100 m" category having an 8 value than the "200 to 300 m" category worth 7 (table 2). Aspect and slope were the other properties requiring interpolation. A southeast aspect on a 7-percent slope was intermediate between "Any aspect when slope 5 percent or less" worth 4 and "S, SE, or SW with slope 10-20 percent" worth 2 and was assigned a value of 3.

**Table 5—Site evaluation for area A**

Soil-site property and site points by factor					
1		2		3	
Geographic and topographic position		Soil moisture and aeration during the growing season		Soil fertility and physical condition	
Elevation	8	Internal drainage	1.5	Parent material	
Physiographic position	3	Texture	1.75	and age	2
Aspect and slope	3	Soil depth	2	pH	2
Precipitation	2	Rock and gravel content	-1	Organic matter	2
Special hazards	0	Depth to water table	1	Bulk density	0
Total	16	Total	5.25	Total	6

Total for all factors = 27.25.  
 $SI_{50} = 27 \text{ m.}$

**Table 6—Site evaluation for area B**

Soil-site property and site points by factor					
1		2		3	
Geographic and topographic position		Soil moisture and aeration during the growing season		Soil fertility and physical condition	
Elevation	7.75	Internal drainage	3	Parent material	
Physiographic position	4	Texture	3	and age	3
Aspect and slope	3	Soil depth	2	pH	2
Precipitation	2	Rock and gravel content	1	Organic matter	2
Special hazards	0	Depth to water table	1	Bulk density	0
Total	16.75	Total	10	Total	7

Total for all factors = 33.75.  
 $SI_{50} = 34 \text{ m.}$

Rounded to the nearest meter, site index or total site rating for area B was 34 m; this area would be a good site for red alder. It achieved 84, 83, and 88 percent of the maximum values for factors 1, 2, and 3. Thus, although area B was less than optimum in all three factors, no one factor or property was identified as having a large potential impact on growth.

## Applicability

These site evaluation tables were developed with data from stands growing west of the crest of the Cascade Range in Washington and northern Oregon (latitude 45°0' to 48°30' N). These tables should not be used outside this geographic area until local users determine the applicability of the tables to their site conditions. For example, it would probably be necessary to modify the site points assigned to specific elevations for use in areas substantially north of the Washington-British Columbia border. In addition, when the user encounters site conditions not widely distributed in the Pacific Northwest—such as soil derived from serpentine rocks—the site evaluation tables should not be used until they are tested. Such nontypical conditions were not sampled in the study; thus, the model does not account for them.

This site evaluation guide was developed from plots located on apparently uniform site conditions. Plot boundaries were laid out to avoid changes in slope, aspect, drainage or other site conditions. The greatest accuracy in prediction of site index will be achieved when users limit their evaluations to areas of similar uniformity. It may be helpful for a user to first roughly map areas that appear to be fairly uniform and then to sample within each of the major divisions or strata. Sampling intensity will vary with the user's need for precision; however, it should be recognized that soil characteristics can be extremely variable and in some areas it may take several point determinations to accurately assess potential site index.

All plots were in natural unmanaged stands. Actual or apparent changes in site quality for red alder associated with forest management (including plantation culture) are not known. In addition, the model does not take genetic variability of the species into account. Apparent increases in site index may be realized in the future when genetically improved plant materials are used. These apparent increases in site index may result from higher overall growth rates associated with some genotypes or from using genotypes with tolerances for specific site conditions. The site evaluation tables (tables 2, 3, and 4) can be used to rank sites in order of potential site index; however, how accurately the tables will predict the actual site index attained under intensive culture cannot be judged until older plantations are available for evaluation.

## English Equivalents

1 cm = 0.394 in  
1 cm<sup>3</sup> = 0.061 in<sup>3</sup>  
1 g = 0.035 oz (avoirdupois)  
1 ha = 2.47 acres  
1 m = 3.281 ft  
1 mm = 0.039 in



## **Acknowledgments**

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## Appendix 1

### Definition of Terms Used in Tables

#### Factor 1

*Elevation:* Mean elevation above sea level in meters. Should be determined to nearest 25 m.

*Precipitation, April 1 through September 30:* Can be determined from weather records or maps of rainfall distribution. Users should try to compensate for differences in precipitation between the site being evaluated and the nearest weather station or map averages. In particular, the effect of elevation on precipitation should be taken into account.

#### *Physiographic position:*

Flood plain—On a level plain associated with a river system, the width of a flood plain is determined by the size of the river and the associated topography. A site should probably not be considered to be on a flood plain unless it is subject to flooding during high water at least once every 10 to 15 years.

Terrace or bench—Site generally level or somewhat rolling with slope less than 15 percent, and far enough from a river or high enough to be rarely or never flooded. Also includes lower slope positions on side slopes when slope is less than 20 percent. In contrast to midslope positions, sites in this category are considered to be in a generally moisture-gaining position.

Midslope—Includes midslope positions and lower slope positions with slope greater than 20 percent. Such sites are considered to have minimal net change in soil moisture; that is, gains in soil moisture caused by additions from upslope positions would be approximately balanced by losses to sites farther down the slope. Would probably be the most common physiographic position encountered.

Marsh or bog—Depression in landscape with limited downward movement of water, often in a position to gain soil moisture from surrounding area.

Upper slope—Side slope positions just below the top of the hill. Considered to have a net loss in soil water but to be less exposed than ridgetop positions.

Ridgetop—Along top of ridge or hill. Considered to have a net loss in soil moisture and to be the position most exposed to wind. True ridgetop positions are the most unfavorable physiographic positions in terms of tree growth. The user should assign a higher value for physiographic position if the site being evaluated is on top of a hill or ridge but is located on a fairly level plateau, is in a minor depression, or is sheltered by surrounding features. The value assigned should be based on the user's evaluation of water movement and wind exposure.

*Special hazards:* Recognition of special hazards and assignment of negative site points can best be done by users with knowledge of local conditions. Sites with special hazards would include those located in frost pockets (either natural or created by cutting). Windy, exposed sites—such as those close to the Pacific Ocean without blocking topographic features, or areas in the vicinity of mountain passes—are examples of other conditions that need to be taken into account.

## **Factor 2**

*Internal drainage:* Well-drained and excessively drained soils should be carefully evaluated for the presence of special soil features; such evaluation can be done from a detailed profile description or from examination of a soil pit.

*Texture:* As determined from a textural triangle after mechanical analysis. With practice, texture can be estimated fairly well in the field, especially with the use of published definitions of soil textural classes based on feel and field experience (Soil Survey Staff 1975).

*Soil depth:* Mean soil depth that roots and water can easily penetrate, can be determined by use of an auger or by examination of a soil pit. The user should try to determine effective rooting depth rather than depth to bedrock.

*Rock and gravel content:* Can be determined by sieving soil samples or by visual and textural examination. If the soil is not compacted and the rocks do not contain a lot of trapped air (for example, pumice or similar material), multiplying the percentage of rock and gravel *volume* by 2 will approximate the percentage of rock and gravel *weight*.

*Depth to water table:* The average depth to water table during the growing season; can be determined by soil boring or by comparison of site elevation in relation to the water level in nearby streams or lakes. Use of intermittent or very shallow streams to evaluate water table level is not recommended.

## **Factor 3**

*Parent material and age:* Published soil survey information can be helpful in determining parent material; however, many categories can be easily recognized in the field.

*pH:* Measure of soil acidity can be determined in the field or on fresh samples in the office with a pH meter or a pH testing kit. Can be estimated from soil survey information if description of mapped soil agrees well with what is observed at the site.

*Organic matter:* The organic portion of a mineral soil composed of plant and animal remains in various stages of decomposition. Most accurately determined in the laboratory, but with practice can be estimated in the field. Surface soils low in organic matter do not differ much in color from lower layers and generally are light colored. Soils high in organic matter are usually very dark in color and both well-decomposed material (greasy feeling) and partially decomposed materials (origin somewhat evident) can be distinguished.

*Bulk density:* Measure of soil compaction expressed as oven-dry soil weight per unit of volume. Most accurately measured with equipment designed for such determination, but with practice can be estimated in the field. Soils with low bulk density are loose, porous, or friable. Soils with high bulk density are tight and strongly compacted.

## Appendix 2

### Site evaluations for red alder

#### Sample Field Worksheet

Site name or number: \_\_\_\_\_

Location: \_\_\_\_\_

Soil-site factors					
1		2		3	
Geographic and topographic position		Soil moisture and aeration during the growing season		Soil fertility and physical condition	
Soil-site property	Score for this site	Soil-site property	Score for this site	Soil-site property	Score for this site
Elevation	_____	Internal drainage	_____	Parent material and age	_____
Physiographic position	_____	Texture	_____	pH	_____
Aspect and slope	_____	Soil depth	_____	Organic matter	_____
Precipitation	_____	Rock and gravel content	_____	Bulk density	_____
Special hazards	_____	Depth to water table	_____		
Total for factor 1 = _____		Total for factor 2 = _____		Total for factor 3 = _____	

Total for all factors = \_\_\_\_\_ .

SI<sub>50</sub> = \_\_\_\_\_ m.



**Harrington, Constance A.** A method of site quality evaluation for red alder. Gen. Tech. Rep. PNW-192. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 22 p.

A field guide to predict site index for red alder (*Alnus rubra* Bong.) was developed for use in western Washington and Oregon. The guide requires the user to evaluate 14 soil-site properties that are grouped into three general factors: (1) geographic and topographic position, (2) soil moisture and aeration during the growing season, and (3) soil fertility and physical condition. Construction of the guide was modeled after a method of site evaluation developed for several southern hardwood species. The red alder model is accurate when used properly. The correlation ( $r$ ) between predicted and measured site index was 0.97 for the basic data set of 25 plots and 0.96 for the 15 plots used for verification. Estimated site index should be within  $\pm 2$  meters of measured site index 95 percent of the time. Use of a second independent data set for model verification resulted in a somewhat lower correlation ( $r = 0.89$ ) between measured and predicted site index than was achieved with the original data set, but the model continued to meet the accuracy standard of  $\pm 2$  meters ( $p \leq 0.05$ ).

Keywords: Site class, site index, guidebooks, models, red alder, *Alnus rubra*.

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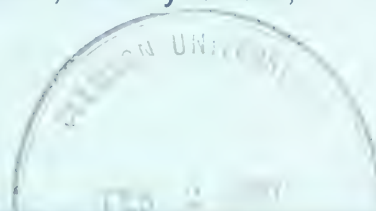
General Technical  
Report  
PNW-193

April 1986



# Users Guide for Seeds of Western Trees and Shrubs

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Scott Wolff, and David Gerdes





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**Cover photo:** Winged seeds of noble fir (*Abies procera* Rehd.) as they appear shortly before the mature cone shatters.

## Abstract

**Stein, William I.; Danielson, Rodger; Shaw, Nancy; Wolff, Scott; Gerdes, David.**  
Users guide for seeds of western trees and shrubs. Gen. Tech. Rep. PNW-193.  
Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest  
Research Station; **1986.** 45 p.

Because the role of tree and shrub seed is indispensable in the renewal of forests and ranges, their identity and quality are critically important. This guide briefly covers recommended practices for maintaining the identity of seeds, for sampling them, and for testing them for quality. Practices associated with the testing and use of tree seed have developed over many years, whereas those for shrub seed are just developing. Selected references, excerpts from official seed testing rules, addresses of seed testing laboratories, and sources of information for shrub seed are included.

**Keywords:** Seed (tree), seed (shrub), seed testing, seed quality.

## Preface

This report is the second revision of a booklet describing sampling and testing procedures for seeds of native western species. It supersedes "Sampling and Service Testing Western Conifer Seeds" published by the Western Forest Tree Seed Council (1966). Previous material has been updated, and selected information has been added on shrub seed, on labeling, and on seed certification. Geographic coverage has been broadened. The authors served as the Seed Testing Subcommittee of the Western Forest and Range Seed Council responsible for this revision.

The Western Forest and Range Seed Council, affiliated with the Western Forestry and Conservation Association, is a voluntary organization whose members share a common interest in tree and shrub seed. Its geographic areas of concern are the 11 westernmost States and British Columbia. The Council's interests were redefined in 1982 to encompass seeds of all forest and range species. Before then, its emphasis was on forest tree seed under the title Western Forest Tree Seed Council.

Pertinent sections of the "Rules for Testing Seeds," published by the Association of Official Seed Analysts in 1981 (with revisions through 1984), are reproduced with permission in appendix 3.

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## Introduction

Large quantities of tree and shrub seed are collected, stored, and sown in the West or are exported. Because their role is vital in the renewal of forests and ranges, the identity and quality of tree and shrub seed are critically important. Procedures have been developed for maintaining the identity of seeds, and workable methods have been prescribed for testing the quality of most species.

The state of the art is described in this booklet for anyone who buys, sells, or uses seeds of western trees or shrubs. Recommended practices for maintaining the identity of seeds, for sampling them, and for testing their quality are covered briefly. Actual collection techniques or detailed procedures related to certification of seed are not covered. An overview is intended; greater detail can be obtained from seed specialists, from sources cited in the text or included in the selected references, and from organizations listed in the appendixes.

Practices associated with the collection, processing, testing, and use of western tree seed, especially conifers, have developed over many years, whereas those for shrub seed are just developing. Consequently, the level of information available differs substantially. Information is presented jointly for tree and shrub seed when possible, but when necessary, applicability to shrub seed is described separately.

## Seed Identity

Large amounts of tree and shrub seed are collected from native wild stands; smaller amounts are collected from genetically improved or tested stands. Correct and adequate identification of seed must start at the collection site and is critically important for seeds collected from any source. It has been demonstrated repeatedly that production of healthy new stands requires use of seed or stock adapted to the site. Maintaining the identity of its source is an essential step in correctly matching seed or stock to site.

Adequate identification of seed requires: (1) correct botanical identification by species and variety, (2) location and elevation of collection area, (3) native origin of the plants that produced the seed, and (4) information available on verified genetic traits. Identification and labeling of a seed lot must begin with a knowledgeable collector recording pertinent information. Because seed origin and genetic traits are so critically important, formal procedures are often used to certify that the information on the label is accurate.

## Labeling Seed

Each container of fruits, cones, or seeds collected in the field should be adequately labeled (fig. 1). As a minimum, the label should indicate the species (and variety, if known), the precise geographic location of the collection, the elevation, the date of collection, and the signature of the collector. Additional information on the label or accompanying the collection may include the State, county, seed zone, soil type, number and description of seed parents, and any special features. Notes on cone maturity, insect damage, or possible poor pollination can also contribute to better understanding and to better processing of a particular seed lot. A durable, legible label should be firmly attached to the outside of each container to insure continuous identity of its contents. An identical label may be placed inside the container if damage to or loss of the outside label seems likely.

Integrity of each collection must be maintained in the field, throughout transport and processing, and during storage and use. This requires physically keeping track of the collection, step by step; preventing its contamination during processing by seeds of other lots; and keeping accurate records of lot description, size, and disposition.



Figure 1.—Identification of seed must start at the collection site and is critically important for seed from any source.

## Seed Collection Zones

Collection zones have proved useful for describing origin of seeds from native stands. Labeling a seed collection by its exact origin is most precise, but such information does not indicate which collections are from similar origins. Delineation of forested areas into zones judged to contain environmentally similar conditions serves this need until supplanted by information from actual studies.

Collection zones for tree seed have been recognized for a decade or more in Arizona, British Columbia, California, New Mexico, Oregon, and Washington (Rudolf 1974), and more recently in Colorado and Wyoming. The zones have been delineated on different bases and have been used to varying extents. If used consistently, they will become more valuable as experience accumulates on performance of seeds from different zones. Seed zone maps for Oregon and Washington are on a common basis; they have been used extensively and will serve as an example (fig. 2). Zone boundaries in Oregon and Washington delineate areas that were considered physiographically and climatically different. Single digits of a three-digit number code designate first the broad geographic zone, then the smaller geographic zone within the broad zone, and third, a local zone. Two digits are added to identify elevation within a zone in 500-foot (150-m) increments. Seed zone maps are improved and revised periodically. Contact the certifying agency in your State or Province for current information on tree seed zone maps.

Origin of genetically improved tree seed is commonly described by its exact parentage, or more broadly, by breeding zones. A breeding zone is the geographic area represented by the parents of progeny in a seed orchard. Seed produced by fertilization that occurs within the orchard represents the geographic area or breeding zone. As information on genetic variation accumulates, both seed zones and breeding zones may eventually be replaced with more precise delineations based on genetic variation or on guidelines for seed movement.





Figure 2.—Seed collection zones for Oregon.

Collection zones have not yet been delineated for shrub seed, but the need to delineate limits for the transfer of shrub seed has been recognized. Preliminary guidelines on adaptability and transfer have been developed for selected shrub populations in the intermountain region from results of field planting trials. Up-to-date information on adaptability and other traits of shrub species is obtainable from many USDA Forest Service and Soil Conservation Service offices, from other Federal and State agencies, and from universities (see appendix 1, p. 24).

## Certification

Formal certification of tree or shrub seed involves independent verification of the information appearing on a seed label. The verified information may include the species and variety, the geographic origin and elevation, the male and female parentage, and sometimes the test results from progeny or clones. Before such information can be certified, actual inspection of seed collection, of processing methods and of record keeping are necessary, as well as audits of the seed lot at various steps in processing and storage.

Certification of tree seed was formalized in Oregon and Washington in 1966 when the Northwest Forest Tree Seed Certifiers Association was formed with the assistance of the Western Forest Tree Seed Council (Hopkins 1968, Stein 1975). In subsequent organizational steps, actual verification work became the responsibility of each State's agricultural seed certification agency. Tree seed certification is now relied on heavily in Oregon and Washington—more than 1 million pounds (453 592 kg) of seed representing 17,743 lots of 26 tree species were certified in the various designated classes by 1983.



Tree seed in Oregon and Washington may be certified as meeting the standards for one of six classes. The classes represent increasing degrees of certainty about the origin and genetic composition of the seed, varying from an audit class (a verification of records showing that the seeds were collected from the stated origin), to procedural or field verification of origin, to selection of one or both parents, or to selected parents whose progeny have been tested and evaluated for genetic improvement (DeYoe 1984).

Certification of tree seed is gaining attention in other Western States and in British Columbia. California and New Mexico have adopted standards very similar to those in the Pacific Northwest. Organizational activity is under way in several other States. Requests for certification of other reproductive materials such as "plus" trees, scions, nursery stock, and plantations are also increasing.

Arrangements have been made for certifying origin of shrub seed in New Mexico and both origin and quality in Colorado. Efforts to develop uniform shrub certification services in the Western States are under way. It has been proposed that four types of shrub populations eventually be recognized: (1) nonselected populations, (2) selected populations, (3) managed populations, and (4) shrub seed orchards from selected parents or named varieties.

Extensive programs for the genetic improvement of tree populations have been underway for years; programs for the improvement of shrub populations are much smaller, but they are expanding. Shrub populations are being tested for desirable characteristics and range of adaptation. A few shrub cultivars have been identified and released for commercial seed production (U.S. Department of Agriculture, Soil Conservation Service 1984). Information on the status of tree or shrub improvement programs is primarily available from such organizations as the Industrial Forestry Association, Inland Empire Tree Improvement Cooperative, State Agricultural Experiment Stations and Extension Services, USDA Forest Service Experiment Stations, and USDA Soil Conservation Service Offices.

State certification agencies certify tree and shrub seed for export under regulations of the Organization for Economic Cooperation and Development (OECD Scheme) to the European Economic Community (EEC) and to other participating countries. In Canada, tree seed is certified under the OECD Scheme by designated units of the Canadian Forestry Service (Piesch and Stevenson 1976).

## **Sampling Seed**

An objective assessment of quality is needed to guide the storage, selling, buying, and use of seed. Quality of seed is determined for a limited sample drawn from the entire lot. There are recommended practices for defining the seed lot, for drawing a representative sample, and for testing the sample of seeds for germination and other quality attributes.

## **The Seed Lot**

A seed lot is generally defined as a quantity of seed from a particular location and elevation (fig. 3). It usually constitutes the total yield from a particular cone or fruit collection transported from the field in bags or containers. Yearly collections of seed from the same location and elevation are usually handled as separate lots. Any lot or portion thereof destined for a specific transaction or use may become a specific entity to be tested for quality.



Figure 3.—A seed lot usually consists of the yearly collection of seed from a particular location and elevation or stand.

Yield of seed from one collection may be stored in a single container, or it may consist of hundreds or thousands of pounds stored in a number of bags or containers. There are no prescribed limits for size of a seed collection; however, the larger the amount, the more difficult it may be to obtain a representative sample. Thus, some practical upper limits have been specified in international and domestic testing conventions (Bonner 1974). In the Pacific Northwest, collections of tree seed that exceed 500 pounds (227 kg) have generally been divided into approximately equal smaller lots. For example, 700 pounds (318 kg) would be sampled as two lots of approximately 350 pounds (159 kg) each. Limits based on similar practical considerations could be used for shrub seed.

## The Sample

A small portion of a seed lot, a sample, is obtained and forwarded to a testing laboratory for specified quality determinations. It is critically important that the sample taken be representative of the entire seed lot because laboratory test results indicate only the quality of the submitted sample. If the sample is representative, the quality determined for the sample accurately reflects the quality of the entire lot.

Drawing a representative sample from a seed lot would be a simple matter if the lot were fully homogenous; any portion of the lot would then constitute a representative sample. Rarely, however, is it certain that a lot is completely homogenous. Consequently, the sampling method must produce a representative sample from a unit of seed assumed to be heterogenous.

A representative sample is obtained by combining portions taken from throughout the seed lot (Association of Official Seed Analysts 1981). It is recommended practice to take equal portions (subsamples) from each bag or container sampled. If bags or containers are of unequal size or fullness, the amount taken from each should be in proportion to its content. If the seed lot is in one to six bags or containers, every one is to be sampled. When there are more than six bags or containers, five should be sampled plus at least 10 percent of the number in the lot, but not more than 30, all designated at random. A bulk seed lot should be sampled to the same intensity as a lot in bags or containers. If a seed lot is packaged in many small packets, entire packets may be used as subsamples.



Subsamples drawn from the seed lot are combined into one composite sample unless a subsample differs distinctly in appearance from other subsamples. If such a nonuniform subsample is found, its source is tagged and the subsample is kept separate but is submitted to the seed laboratory with the rest of the sample.

If the composite sample contains substantially more seeds than are needed, it may be divided. Use of a proven mechanical halving device is recommended because it is critically important to achieve an unbiased subdivision of the sample. No impurities—rocks, stems, damaged seeds, weed seeds, and so forth—are to be removed! It is mandatory that the composite sample, or any subdivided portion, continue to be truly representative of the seed lot sampled.

### **Sampling Mechanics**

Bags or containers of free-flowing seed are generally sampled with a partitioned probe or trier (fig. 4). The tool should be long enough that seeds can be drawn from all depths within the container. The probe or trier should be inserted closed, then opened so its slots admit seeds simultaneously from different positions in the container. If a container is sampled by one probe thrust only, a diagonal path is recommended. If probed more than once, successive thrusts should be along different paths.

Seeds that are not free flowing, such as cedars, true firs, and various shrub species are usually sampled by hand. The hand, open and with the fingers held closely together, is inserted into the seeds, closed, and withdrawn holding a representative subsample. Handfuls of seeds are drawn from well-separated points within each container sampled, giving due attention to proportional sampling.

Seed lots too small for sampling with a trier or by hand can be sampled by systematically dividing the lot itself. Several kinds of mechanical dividers are available; the most widely used ones in the United States are the Gamet Precision and Boermer dividers (fig. 5).<sup>1/</sup> Other sampling techniques for small lots include "random cups," "spoon," and "modified halving" (International Seed Testing Association 1976b).

### **Sample Size**

The size of the sample to be submitted for testing depends on the number and type of tests desired. A germination test requires a minimum of 600 seeds; about 2,500 are required for a complete analysis for purity, germination, and weight per thousand seeds (Association of Official Seed Analysts 1981). When additional or special tests are requested, the sample submitted must be suitably larger. Also, if purity or viability is low, or any other condition that might necessitate retesting is suspected, the submitted sample should be at least double the minimum size. A generous sample permits the seed laboratory to use mechanical dividers to obtain the working sample.

One to two ounces (28 to 56 g) of seed are required for moisture determination. The size of sample needed increases for species with larger seeds. This sample must be submitted separately in a moisture-proof container.

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<sup>1/</sup> The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture of any product or service to the exclusion of others that may be suitable.



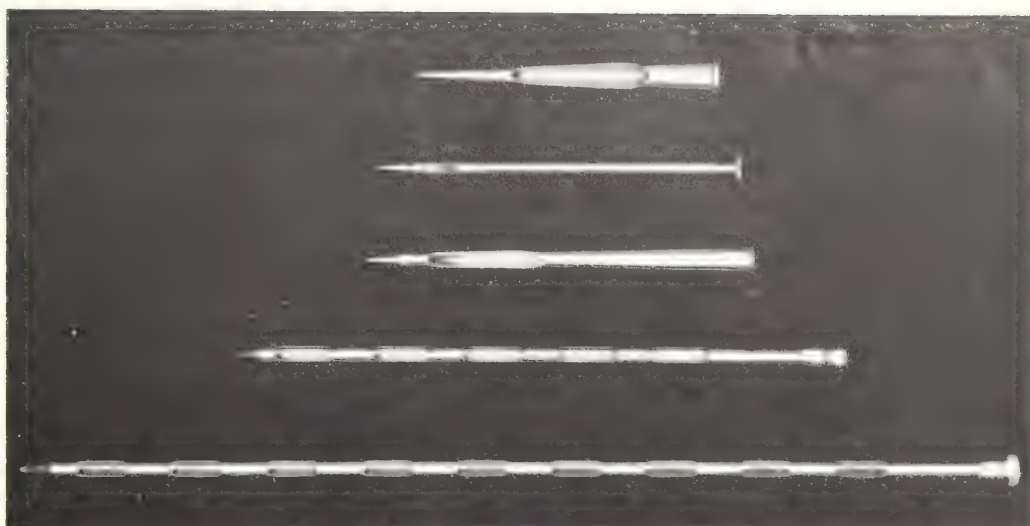


Figure 4.—Probes or triers of appropriate length are used to sample free-flowing seeds in bags or containers.

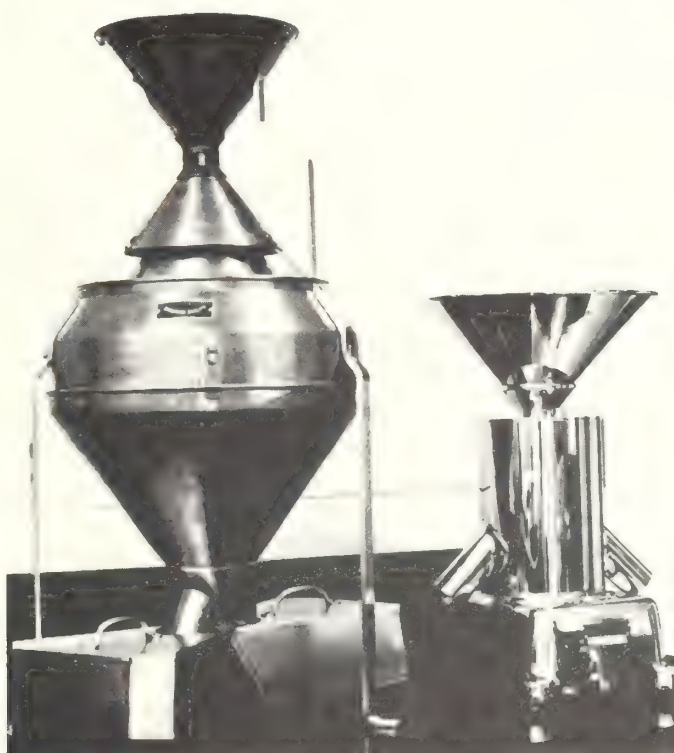


Figure 5.—Mechanical dividers can be used to sample a small lot or to split an oversize sample.

Directions provided by the seed testing laboratory usually include the number of seeds required for any special test. Estimated weight of seeds for the number required can be determined from table 1 in appendix 3 (p. 28); can be calculated from data in Agriculture Handbook 450 (Schopmeyer 1974); or can be determined from a sample of the seed itself. Number of seeds per unit weight varies by purity, moisture content, source, collection year, and other factors.

## Care of Seed

Tree and shrub seed are perishable biological materials. From the time of collection, seeds must be handled, processed, stored, and used under reasonable environmental and physical conditions, or they may quickly lose viability. Seeds of individual species vary greatly in physical structure, strength of outer coat, and the environmental extremes they can withstand. Information on characteristics of many species and specifics for handling each can be found in Agriculture Handbook 450 (Schopmeyer 1974) or in other sources (Eddleman 1977, 1980; Heit 1970, 1971; Plummer and others 1968; Stevens and others 1981; Swingle 1939; Vories 1981; Wasser 1982).

Viability of most western tree and shrub seed can be maintained while they are shipped and prepared for testing if the sample is handled gently, if favorable moisture conditions are maintained, and if exposure to extreme temperatures is avoided. A good estimate of quality can be obtained only if both the seed lot and the sample drawn from it are given suitable care during the testing period. Thus, ongoing handling and storage practices should be maintained for the entire seed lot while the sample from it is being tested.

It is best but not always possible to draw and package a sample of seed under storage conditions. If seed is in cold storage and is not in moisture-proof containers, samples for moisture determination must be drawn, packaged, and sealed under the storage conditions. Otherwise, moisture will condense on the cold seeds when they are exposed to warmer air, increasing their weight and their apparent moisture content. Seed in moisture-proof containers may be removed from storage and allowed to equilibrate to room temperature before the containers are opened and a sample is taken for moisture determination.

## Submitting Samples

Seed samples should be carefully labeled, adequately packaged, and immediately forwarded to the testing laboratory. A plastic bag or a closely woven cloth bag makes a suitable inside container which should be enclosed in a strong rigid container for shipment. The bag of seeds should be snugly packed in the shipping container to prevent free movement of individual seeds. Samples for moisture determination or any samples of seed requiring high moisture content should be sent in full or nearly full moisture-proof containers. Metal cans with grooved friction lids or sealable plastic bags 5 mil or more in thickness make satisfactory moisture-proof containers.

Each sample shipped should be carefully labeled with the sender's name and seed lot identification. One copy of this information should be included in the shipping container. It is good practice to send another copy, including test instructions, independent of the seed shipment. Some laboratories furnish forms on which the customer designates tests desired and records pertinent information about the seed lot.

If the sample contains treated seeds, appropriate precautionary information should be prominently displayed on a separate label. The information should include name of the chemical, harmfulness of the residue, and date of treatment. A strong plastic bag should enclose whatever bag or packet holds the sample of treated seeds.

Seed samples will be checked for quantity, condition, and instructions when they are received by the testing laboratory. If containers were broken or torn in shipment, resulting in damaged seeds or intermixed samples, replacement samples will be requested. If the submitted sample does not contain sufficient seeds for the tests requested, it will be held in storage long enough to permit the sender to supply additional seeds or new instructions. Unused portions of submitted samples are usually held in nonrefrigerated storage for 6 to 36 months. If such storage is suitable for the species, the samples could be retested, if necessary; otherwise, the seed lot would have to be resampled.

## Seed Testing

The primary purpose for testing seeds is to determine their quality. The elements of seed quality measured most often are purity, germination or viability, moisture content, weight per thousand, and attributes revealed by X-ray.

### Rules for Testing Seeds

Procedures for testing various kinds of seed, including tree and shrub seed, are described in two publications. "Rules for Testing Seeds," published in 1981 by the Association of Official Seed Analysts (AOSA), is the primary reference used by seed analysts throughout the United States and Canada. These rules are revised periodically to include new species and procedures. The rules promote uniformity in testing so that seed quality as determined by different laboratories will be comparable. "International Rules for Seed Testing," published in 1976 by the International Seed Testing Association (ISTA), is used by seed analysts in many foreign countries. AOSA and ISTA rules are similar, but there are certain differences. A shipper may choose to request an ISTA test so that a foreign buyer will more readily accept the test. Most laboratories can perform either AOSA or ISTA tests.

Sections of the AOSA rules pertaining to tree and shrub seed are in appendix 3. These excerpts are for the readers' information and convenient reference. Persons specializing in seed testing should obtain the complete AOSA rules. Contact your nearest State seed testing laboratory (appendix 2) for up-to-date information on AOSA and ISTA rules. Some, but not all, State laboratories test tree and shrub seed.

## Purity

Purity expresses the composition of a seed lot and its degree of contamination by unwanted components. A purity test involves the mechanical separation of a working sample into (1) pure seed, (2) other crop seed, (3) weed seed, and (4) inert matter (fig. 6). The four components are then weighed and percentages are calculated on the basis of the original weight if the working sample weighed 25 grams or more, or on the sum of the weights of component parts if the working sample weighed less than 25 grams (appendix 3, section 2.5).

The size of the sample to be analyzed for purity varies with species; as a general rule, approximately 2,500 seeds (or their equivalent weight) should be examined (appendix 3, sections 2.3 to 2.4).

The component "other crop seed" includes seeds of species normally grown for crops that occur in amounts of 5 percent or less. When another crop seed occurs in amounts greater than 5 percent, the sample is referred to as a mixture and that other crop seed becomes part of the mixture. Inert matter includes soil, plant parts, and certain types of damaged seeds. Refer to appendix 3, sections 2.7 to 2.10, for detailed definitions of the four purity components.





Figure 6.—In a purity analysis, the working sample is divided into component parts—pure seed, other crop seed, weed seed, and inert matter.

Before the purity test is made, the submitted sample must be repeatedly mixed and then properly divided to obtain a representative subsample (working sample) of appropriate size. Such efforts insure that the purity test will reflect the true composition of the submitted sample.

## Germination

A germination test determines the capability of a seed lot to produce normal seedlings under favorable, controlled conditions. It involves a minimum of 400 seeds selected at random from the pure seed fraction after seeds of other crops, weed seeds, and inert matter have been removed. The 400 seeds are usually tested in units of 50 or 100 seeds each (fig. 7). Often, a paired test is made so that the user can evaluate seed performance with and without prechilling. When paired tests are run, it is common to germinate either 200 or 400 seeds without prechilling and 200 or 400 after prechilling.

Not every seed that germinates is included in the germination count; only those defined as normal by seed testing rules comprise the germination percent (fig. 8). Albino seedlings and various other abnormal germinants are not counted (appendix 3, section 4.5, and appendix I of the testing rules). Percent germination is calculated for each replicate by this formula:

$$\text{Percent germination} = \frac{\text{number of normal seedlings}}{\text{number of seeds sown}} \times 100.$$

The average for the replicates tested is reported as the germination percent for the sample.

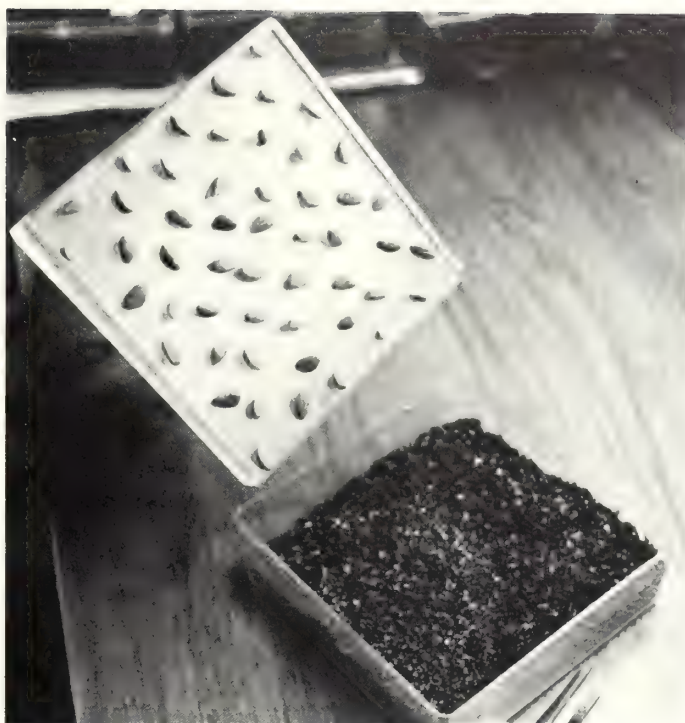


Figure 7.—A vacuum plate is used to place seeds in a germination dish.



Figure 8.—A germination test determines capability of a seed lot to produce normal seedlings under favorable, controlled conditions.

If firm ungerminated seeds remain at the end of the prescribed test period, their presence is reported. Seeds remaining intact are cut with a razor blade or otherwise tested for viability; those with solid, white kernels and normal structure are considered firm. Firm seeds are usually dormant; if so, they will germinate when their dormancy is overcome. Large numbers of firm seeds at the end of the germination test indicate to the user that a longer prechilling period, a different pretreatment, or different germination conditions may be necessary for the seed lot. Persons evaluating germination results may consider adding firm seeds to the germination percent in assessing the total potential viability of a lot.

Speed of germination is an important quality to consider when seedlings are to be raised in a nursery or greenhouse. Many laboratories report weekly counts so that their customers can evaluate speed of germination. If you wish to find the recommended test conditions for germination of a particular species, refer to appendix 3, sections 4.9 and 4.12. Locate the kind of seed, then read from left to right to determine substrata, germination temperature, length of germination test, and additional directions such as length of chill, light requirements, and so forth. For species not yet included in AOSA rules, helpful information may be found in Agriculture Handbook 450 (Schopmeyer 1974); in publications by Eddleman (1980), Tiedemann and others (1984), Vories (1981), Wasser (1982); or by contacting local seed laboratories.

## Quick Viability Tests

Seed viability or germination potential can be quickly estimated by several methods. Such methods, used when there is not enough time for a germination test, are often referred to as "quick" tests. Quick tests can be classed as chemical, growth, and appearance tests. The concepts, procedures, and utility of the main ones have been summarized by Danielson (1972).

**Tetrazolium or TZ test.**—The most popular chemical viability test is the tetrazolium or TZ test, in which live tissues stain red (fig. 9). It is one of the most rapid quick tests, requiring 24 to 48 hours to complete. The TZ test is particularly useful for determining viability of very dormant seeds that would otherwise require months of chilling or other lengthy pretreatment to overcome dormancy. Many laboratories routinely conduct TZ tests "in-house" on samples showing low germination to verify germination test results. The TZ test enables them to evaluate the causes for low germination such as dormancy, dead or dying tissues, empty seeds, presprouting, mechanical injury, and inadequate germination test procedures.

There is evidence that the TZ test provides an equal or even a better estimate of viability for some species than the standard germination test does. Hardin (1981) compared TZ and germination test results for seeds of several trees and bitterbrush and reported excellent correlations except for *Abies*. Viability of *Abies* species as indicated by TZ test is often higher than indicated by germination test. In some instances, emergence in the nursery has been closer to TZ than to germination test results.

Tetrazolium testing procedures for tree and shrub seed have not yet been standardized on a national or regional level. Experience has shown that small variations in technique may have a significant impact on results. For example, when the Oregon State University Seed Laboratory changed from making a slice across the cotyledon end of conifer seeds to a vertical slice that exposed more megagametophyte tissue, TZ penetrated more uniformly and results were more reliable and reproducible. Procedures for TZ testing of agricultural seed are given by Grabe (1970); techniques for conifers and shrubs are obtainable from some seed testing laboratories and at workshops.





Figure 9.—Through metabolic processes, living tissue exposed to a colorless tetrazolium solution stains red, permitting identification of fully healthy endosperms and embryos, and those that are not alive or have various amounts of dead tissue. Views of Douglas-fir (A), noble fir (B), cliffrose (C), and ceanothus (D) treated with TZ show, right to left, a seed sliced open, a healthy embryo, a partly living embryo, and a dead embryo.

**X-ray test.**—Many aspects of quality can be evaluated from X-ray pictures of seed (fig. 10). Information obtainable simply from appearance includes (1) structure and development of individual seeds, (2) full and empty seeds, (3) insect-infested seeds, and (4) seed coat and internal mechanical injuries. When used to determine filled and empty seeds, X-ray is much more accurate than the older "cut" test.

European analysts determine seed viability with X-ray by use of such contrast agents as barium chloride and sodium iodide. Use of contrast agents is also gaining popularity in the United States. The technique is based on differential absorption. Nonviable seed tissue soaked in a contrast agent is more absorbant than viable tissue, making possible differentiation between the two on X-ray film. Damage arising from bruises, insects, and other reasons can also be detected. An excellent reference on radiographic analysis of agricultural and tree seed has been published by the Association of Official Seed Analysts (Belcher and Vozzo 1979).



Figure 10.—Characteristics of individual seeds can be determined nondestructively by X-ray, as is illustrated by these Shasta red fir seeds: column 5 (on the right), top to bottom—embryos of the second, third, fourth, and sixth seeds are partly consumed by insect larvae; column 4, fifth seed—kernel entirely consumed by insect larva; column 1 (first seed), column 3 (third seed), and column 4 (third seed)—hollow seeds; column 2, third seed—seed misshapen, contents appear shriveled.

**Hydrogen peroxide test.**—The hydrogen peroxide test ( $H_2O_2$ ) is classed as a growth test because there is root growth during the test period. For this reason, it is preferred by some over the TZ test. It is also less expensive than the TZ test because it requires less work. Seeds are placed in dilute hydrogen peroxide after removing enough of the radicle end of the seed to expose the tip of the root. During the ensuing 5- to 8-day soak period, viable seeds react by elongation of their roots. Ching and Parker (1958) described the basic procedures.

**Excised embryo test.**—The excised embryo test is also a growth test and is preferred by some because it involves no chemicals and relies strictly on a critical evaluation of the embryo. Basically, embryos are removed from seeds and are incubated under favorable temperature and light conditions. Greening and growth indicate embryo viability. Testing the viability by means of excised embryos requires substantial skill and closely controlled growth conditions. Heit's (1955) paper is a good basic reference.

**Cut test.**—In some circumstances, a cut test is useful for very roughly estimating seed quality. A number of seeds are cut in half lengthwise with a sharp knife or razor blade and the percentage that have full, firm, whitish endosperm is determined. The relative size of the embryo can also be observed. The cut test is often used as an immediate check of seed quality in the field or during various steps in processing. It indicates what percentage of the seeds are filled or have normal embryos, but actual viability remains unknown.

## Other Quality Tests

**Seed moisture content.**—Moisture content is one of the most important factors influencing seed viability. For many species, high moisture during storage results in rapid loss of seed viability. Moisture content of most conifer seeds should be 9 percent or less prior to storage; 5 to 7 percent appears best (Danielson and Grabe 1973, Wang 1974).

Seed moisture content can be measured by several methods. The oven-dry method is one of the most accurate; seeds are dried in an oven after their wet weight has been determined. In 24 to 48 hours at temperatures near 85 °C, water within the seeds is driven off. The seeds are then cooled in a desiccator and reweighed. The difference between the two weights is the weight of water lost. Moisture content is calculated by substituting weight values in the formula:

$$\text{Percent seed moisture} = \frac{\text{weight of water lost, grams}}{\text{original wet weight, grams}} \times 100.$$

Note that seed moisture content is calculated on the basis of the original wet weight of the seeds rather than on their dry weight, as is used in determining moisture content of soils.

A variety of meters are available for determining seed moisture content. They provide rapid estimates, but many are not calibrated for tree or shrub seed. It is advisable to compare meter readings with oven-dry results to check the meter and, if necessary, to calibrate it.

For accurate determination of seed moisture content, loss of moisture must be avoided prior to the initial weighing. Care in handling and packaging has already been emphasized; prompt weighing of seed after the sealed package has been opened is also mandatory. Seeds of certain species contain volatile oils and resins. ISTA rules prescribe special procedures for determining moisture content of such species. Consult a seed testing laboratory for the specifics of special moisture tests.



**Seed weight.**—Information on weight of seed is most useful for calculating sowing densities. Weight is often expressed per 1,000 pure seeds. From weight per thousand, the number of seeds per pound or per kilogram can readily be calculated. For example, if the weight of 1,000 pure seeds is 12.50 grams, the number of pure seeds per pound can be calculated by the ratio:

$$\frac{\text{Number of seeds per lb}}{453.59 \text{ grams}} = \frac{1,000 \text{ seeds}}{12.50 \text{ grams}};$$

$$\text{number of seeds per lb} = \frac{1,000 \times 453.59}{12.50};$$

$$\text{number of seeds per lb} = 36,287.$$

## Seed Commerce

The market value of seed is directly affected by results of purity and germination or viability tests. Other factors, such as scarcity, certification class, quantity, and special processing may also influence the value of a seed lot. Because germination or viability test results are only estimates of the seedling potential for a lot, some interpretation of test results is usually necessary. Practices commonly accepted in seed transactions are described briefly below.

## Interpreting Test Results

Because dormancy varies among lots, seeds of some species are often tested for germination both with and without prechilling. Generally, the highest value obtained in such dual tests is accepted as indicative of the germination potential for the seed lot. Test results that reflect full viability of the lot, such as tetrazolium staining and excised embryo, may indicate higher potential than is indicated by germination test because the latter excludes dormant seeds and abnormal seedlings. Results of cut tests also tend to be higher than germination tests because they determine if healthy appearing endosperm and embryo are present, but not actual viability or germination potential. Neither viability nor germination test results indicate precisely how a seed lot will perform under various field conditions, but results of laboratory germination tests have generally been considered the best indicator. Rapid viability and X-ray tests are becoming more reliable, and when they are properly performed and evaluated, results may deserve equal consideration with those of germination tests (Hardin 1981).

Firm ungerminated seeds often remain after completion of a standard germination test. Testing laboratories report separately the percent germination and the percent firm ungerminated seeds. It is possible that firm ungerminated seeds would have germinated if given more time, longer prechilling, or more suitable germination conditions. In seed transactions, the accepted potential of a seed lot may be the percent germination or the sum of the percent germination and the percent firm ungerminated seeds.

In addition to providing the basis for pricing or sowing a seed lot, germination test results provide other useful information. Rate, vigor, and uniformity of germination and duration of the germination period are helpful indicators of seed quality and response. The amount of firm ungerminated seed or deteriorated seed may signal the need for a longer or shorter chilling period. Seed analysts and seedsmen are good sources of assistance for interpretation of test results.

**Pure Live Seed**

When a seed lot is nearly pure, which is attainable for many tree and shrub seed, it is often priced and bought or sold directly on the basis of the germination or viability percent. For practical purposes, minor impurities can be ignored. But if substantial amounts of impurities (other crop seed, weed seed, and inert matter) are present, a common basis is needed for comparing and pricing seed lots that differ in purity and viability. Equable comparisons can be made by expressing quality and value of each lot on a pure live seed (PLS) basis, as follows:

$$\text{Percent PLS} = \frac{\text{percent germination or viability} \times \text{percent purity}}{100} ;$$
$$\text{price per lb PLS} = \frac{\text{price per lb for impure seed}}{\text{percent pure live seed} \div 100} .$$

The number of pure live seed per pound is calculated as:

$$\text{Number PLS per lb} = \text{number of pure seed per lb} \times \frac{\text{percent germination or viability}}{100} .$$

Many shrub seeds are marketed on a pure live seed basis. Sometimes the minimum acceptable quality for tree seed, or incentives for high quality, has also been set on a pure live seed basis.

**Processing Standards**

Production of clean seed of high viability is a universal goal of the seed industry. Generally attainable minimums for purity and viability of many tree and shrub species are listed in table 1. For storage, seeds of most conifers should have a moisture content of 5 to 9 percent, wet-weight basis. Moisture content requirements for storage of western shrub and hardwood seed are not as well defined. Seeds of many shrub species store satisfactorily in warehouses at ambient temperatures (Plummer and others 1968, Stevens and others 1981); for these, initial moisture content in the same range as for conifers appears satisfactory (fig. 11). Some shrub and hardwood seed require cold storage, and others require conditions that preserve high moisture content.

Initial moisture content required for satisfactory dry storage of seed depends somewhat on intended length and method of storage, as well as on species requirements (Stein 1974). Slightly higher moisture levels are tolerable for storage near or below freezing, but the upper limits on suitable moisture content have not been defined. Generally, the higher the storage temperature, the more detrimental high moisture content is likely to be.

When a lot contains many unfilled seeds, there is concern that the moisture content determined for the lot may not adequately reflect the moisture content of the live, filled seeds. Since unfilled seeds are likely to hold less moisture in their seed coats than is held in the seed coats plus endosperms and embryos of filled seeds, moisture content for filled seeds may be higher than the average determined for the lot. Actual differences for lots with different percentages of filled seed have not been determined. This concern applies particularly to *Abies* species and to several shrubs where the percentage of filled seed may often be unavoidably low.

Table 1—Recommended minimum standards for purity and viability of tree and shrub seed<sup>1/</sup>

Species			
Scientific name	Common name	Purity	Viability
- - Percent - -			
TREES			
<i>Abies amabilis</i>	Pacific silver fir	95	35
<i>Abies concolor</i>	White fir	95	40
<i>Abies grandis</i>	Grand fir	95	40
<i>Abies lasiocarpa</i>	Subalpine fir	95	35
<i>Abies magnifica</i> var. <i>shastensis</i>	Shasta red fir	95	40
<i>Abies procera</i>	Noble fir	95	40
<i>Alnus rubra</i>	Red alder	95	60
<i>Amelanchier alnifolia</i>	Western serviceberry	95	85
<i>Cercocarpus ledifolius</i>	Curleaf cercocarpus	90	80
<i>Cercocarpus montanus</i>	Alderleaf cercocarpus	90	80
<i>Chamaecyparis lawsoniana</i>	Port-Orford-cedar	95	50
<i>Chamaecyparis nootkatensis</i>	Alaska-cedar	95	35
<i>Cornus stolonifera</i>	Red-osier dogwood	95	85
<i>Cowania mexicana</i>	Cliffrose	95	85
<i>Crataegus douglasii</i>	Black hawthorn	95	70
<i>Elaeagnus angustifolia</i>	Russian-olive	98	90
<i>Gleditsia triacanthos</i>	Honeylocust	98	80
<i>Juniperus osteosperma</i>	Utah juniper	98	60
<i>Juniperus scopulorum</i>	Rocky Mountain juniper	98	60
<i>Larix occidentalis</i>	Western larch	90	60
<i>Libocedrus decurrens</i>	Incense-cedar	90	50
<i>Picea brewerana</i>	Brewer spruce	95	80
<i>Picea engelmannii</i>	Engelmann spruce	95	80
<i>Picea sitchensis</i>	Sitka spruce	95	80
<i>Pinus attenuata</i>	Knobcone pine	98	80
<i>Pinus contorta</i>	Lodgepole pine	98	80
<i>Pinus jeffreyi</i>	Jeffrey pine	98	80
<i>Pinus lambertiana</i>	Sugar pine	98	80
<i>Pinus monticola</i>	Western white pine	98	80
<i>Pinus ponderosa</i>	Ponderosa pine	98	80
<i>Prunus americana</i>	American plum	98	70
<i>Prunus virginiana</i>	Chokecherry	98	70
<i>Pseudotsuga menziesii</i>	Douglas-fir	98	80
<i>Rhus glabra</i>	Smooth sumac	90	40
<i>Sambucus cerulea</i>	Blue elder	95	50
<i>Sequoia sempervirens</i>	Redwood	90	25

See footnotes at



**Table 1—Recommended minimum standards for purity and viability of tree and shrub seed<sup>1/</sup> (continued)**

Species			
Scientific name	Common name	Purity	Viability
		- - <u>Percent</u> - -	
<i>Sequoiadendron giganteum</i>	Giant sequoia	90	40
<i>Shepherdia argentea</i>	Silver buffaloberry	98	80
<i>Thuja plicata</i>	Western redcedar	95	60
<i>Tsuga heterophylla</i>	Western hemlock	98	70
<i>Tsuga mertensiana</i>	Mountain hemlock	98	70
SHRUBS			
<i>Amorpha canescens</i>	Leadplant amorphia	95	90
<i>Artemisia nova</i>	Black sagebrush	<sup>2/</sup> 10	80
<i>Artemisia tridentata</i>	Big sagebrush	<sup>2/</sup> 10	80
<i>Atriplex canescens</i>	Fourwing saltbush	95	50
<i>Atriplex confertifolia</i>	Shadscale saltbush	95	35
<i>Atriplex gardneri</i>	Gardner saltbush	95	45
<i>Atriplex lentiformis</i>	Big saltbush	90	70
<i>Atriplex polycarpa</i>	Cattle saltbush	90	40
<i>Caragana arborescens</i>	Siberian peashrub	95	90
<i>Ceanothus sanguineus</i>	Redstem ceanothus	98	85
<i>Ceanothus velutinus</i>	Snowbrush ceanothus	98	85
<i>Chrysothamnus nauseosus</i>	Rubber rabbitbrush	<sup>2/</sup> 12	75
<i>Colutea arborescens</i>	Common bladdersenna	98	65
<i>Cotoneaster acutifolia</i>	Peking cotoneaster	98	80
<i>Ephedra viridis</i>	Green ephedra	95	85
<i>Eriogonum heracleoides</i>	Wyeth eriogonum	95	75
<i>Eurotia lanata</i>	Common winterfat	50	85
<i>Fallugia paradoxa</i>	Apacheplume	80	75
<i>Grayia spinosa</i>	Spiny hopsage	90	80
<i>Kochia prostrata</i>	Prostrate summercypress	90	90
<i>Lonicera tatarica</i>	Tatarian honeysuckle	90	85
<i>Potentilla fruticosa</i>	Bush cinquefoil	70	70
<i>Prunus besseyi</i>	Bessey cherry	98	70
<i>Purshia tridentata</i>	Antelope bitterbrush	95	90
<i>Rhus trilobata</i>	Skunkbush sumac	95	40
<i>Ribes aureum</i>	Golden currant	95	65
<i>Rosa woodsii</i>	Woods rose	95	70
<i>Sarcobatus vermiculatus</i>	Black greasewood	85	40

See footnotes at end of table.

**Table 1—Recommended minimum standards for purity and viability of tree and shrub seed<sup>1/</sup> (continued)**

Species			
Scientific name	Common name	Purity	Viability
- - Percent - -			
<i>Spiraea douglasii</i>	Douglas spirea	80	80
<i>Symphoricarpos albus</i>	Common snowberry	95	80
<i>Symphoricarpos oreophilus</i>	Mountain snowberry	95	80
<i>Syringa vulgaris</i>	Common lilac	90	70

<sup>1/</sup> Recommended standards for conifers developed by consensus among members of the Western Forest and Range Seed Council. Minimums for shrubs and hardwood trees are based on data published by Plummer and others (1968), Wasser (1982), and on a compilation by Kent R. Jorgensen that is part of an Agriculture Handbook in preparation for publication.

<sup>2/</sup> Suitable levels for range seedlings. Minimum purity of 50 percent is recommended for nursery seedlings of *Artemisia* species and 40 percent for *Chrysothamnus* species.



Figure 11.—Many shrub seed store well in warehouses at ambient temperatures (A); conifer seed are generally stored at temperatures below freezing (B).

## Phytosanitary Certificate

Seed destined for export must usually be certified as being free of harmful insects and diseases. Such certificates are import requirements of the country receiving the seed. The appropriate forms are usually provided by the importer, and the actual inspection of the seed is conducted by federally licensed inspectors. Contact your State department of agriculture for the location of the nearest office where phytosanitary inspections are made and for the quarantine requirements of individual countries.

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Public Sources of  
information on Native  
Shrubs

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USDA Soil Conservation Service  
3241 Romero Road  
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1688 W. Adams, Room 414  
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### Appendix 3

#### Sections of Official Testing Rules Most Pertinent to Tree and Shrub Seed

Sections of the Association of Official Seed Analysts (1981) rules for testing seeds are reproduced for the reader's information and for convenient reference. Most excerpts include full sentences; nonpertinent parts of paragraphs and entire subsections have been omitted (shown by ellipses). The numbering system used in the AOSA rules has been retained to facilitate quick referencing to the full rules. Persons who need more information and those specializing in seed testing should obtain a set of current rules. Information on where to obtain the official rules can be provided by your nearest State seed testing laboratory (appendix 2).

The following sections are reproduced from pages 1 to 116 of "Rules for Testing Seeds" (Association of Official Seed Analysts 1981, with revisions through 1984); titles of "continued" tables may not appear where they do in the original "rules":

## 1. SAMPLING

### 1.4 Size of submitted sample

- a. *For composite sample to test for quality.*—The following are minimum weights for samples of seed to be submitted for purity, germination and noxious weed seed examination:

- (6) Tree and shrub seed samples shall consist of at least 600 seeds per sample for germination purposes. If a purity analysis or a noxious-weed seed examination is required, the submitted sample shall provide at least the minimum weights of working samples set forth in section 2.4.

## 2. ANALYSIS OF THE SEED

The analysis for purity and the test for germination for law enforcement, labeling, and general information as to seed quality, should determine for the sample analyzed: (1) the purity composition, including an identification to determine the kind of seed, and if possible from appearance, the varietal composition; (2) the rate of occurrence of noxious-weed seeds per unit weight; and (3) the percentage germination of the pure seed under consideration.

### 2.2 Obtaining the working sample

The working sample on which the actual analysis is made shall be taken from the submitted sample in such a manner that it will be representative. The sample shall be repeatedly divided to the weight to be used for the working sample. Some form of efficient mechanical divider should be used. In case the proper mechanical divider is not available, the sample shall be thoroughly mixed and placed in a pile and the pile shall be repeatedly divided into halves until a sample of the desired weight remains. To avoid damage to large seed, caution should be observed to prevent them from falling great distances on hard surfaces.

### 2.3 Weight of working samples

- a. *Kinds of seed listed in Table 1.*—The weight of the working samples for the purity analysis and noxious-weed seed examination shall not be less than that prescribed in Table 1, except as noted in c below.
- b. *Kinds of seed not listed in Table 1.*—The weight of the purity working sample and its corresponding noxious-weed seed working sample may be determined from Table 1 by a kind of seed that is similar in size and weight, and which would provide approximately 2,500 seeds in the purity working sample.



c. In samples that are believed to be unusually small-seeded or large-seeded for the kind being tested.—The size of the purity working sample may be based on a sample containing no less than 2,000 seeds without regard to the weight specified in Table 1, provided that in no case shall less than one-fourth gram be analyzed.

#### 2.4, Table 1. \* \* \*

Table 1. Weights for working samples, TREE and SHRUB SEEDS

Kind of seed	Minimum weight for purity analysis <sup>a</sup>	Approximate number of seeds per gram <sup>b</sup>	Approximate number of seeds per ounce <sup>c</sup>
	Grams	Number	Number
<i>Abies amabilis</i> (Loudon) Forbes Pacific silver fir	100	25	705
<i>Abies balsamea</i> (L.) Miller balsam fir	20	130	3,740
<i>Abies concolor</i> (Gordon) Hildebrand white fir	75	35	995
<i>Abies fraseri</i> (Pursh) Poiret fraser fir	20	125	3,500
<i>Abies grandis</i> (D. Don) Lindley grand fir	50	50	1,450
<i>Abies homolepis</i> Siebold & Zuccarini nikko fir	40	65	1,780
<i>Abies lasiocarpa</i> (Hooker) Nuttall subalpine fir	30	85	2,340
<i>Abies magnifica</i> A. Murray California red fir and Shasta red fir (var <i>shastensis</i> )	200	13	355
<i>Abies procera</i> Rehder noble fir	80	30	915
<i>Abies veitchii</i> Lindley veitch fir	20	130	3,680
<i>Acer ginnala</i> Maximowicz amur maple	75	35	950
<i>Acer macrophyllum</i> Pursh bigleaf maple	350	7	195
<i>Acer negundo</i> L. boxelder or negundo maple	100	25	710
<i>Acer pensylvanicum</i> L. striped maple	100	25	710
<i>Acer platanoides</i> L. Norway maple	400	6	165
<i>Acer pseudo-platanus</i> L. sycamore maple	200	13	370
<i>Acer rubrum</i> L. red maple	50	50	1,420

Table 1. Weights for working samples, TREE and SHRUB SEEDS (continued)

Kind of seed	Minimum weight for purity analysis <sup>a</sup>	Approximate number of seeds per gram <sup>b</sup>	Approximate number of seeds per ounce <sup>c</sup>
	Grams	Number	Number
<i>Acer saccharinum</i> L. silver maple	500	3	90
<i>Acer saccharum</i> Marshall sugar maple	175	14	380
<i>Acer spicatum</i> Lamarck mountain maple	50	50	1,420
<i>Ailanthus altissima</i> (Miller) Swingle tree of heaven or ailanthus	80	30	915
<i>Berberis thunbergii</i> DC. Japanese barberry	40	60	1,690
<i>Berberis vulgaris</i> L. European barberry	30	85	2,340
<i>Betula alleghaniensis</i> Britton yellow birch	3	985	27,900
<i>Betula lenta</i> L. sweet birch	2	1,420	40,400
<i>Betula nigra</i> L. river birch	3	825	23,400
<i>Betula papyrifera</i> Marshall paper birch	1	3,040	86,300
<i>Betula pendula</i> Roth European white birch	1/2	5,290	150,000
<i>Betula populifolia</i> Marshall gray birch	1/2	9,380	266,000
<i>Catalpa bignonioides</i> Walters southern catalpa	50	45	1,280
<i>Catalpa speciosa</i> (Barney) Engelman northern catalpa	50	45	1,280
<i>Cedrus atlantica</i> (Endlicher) Carriere Atlas cedar	200	12	350
<i>Cedrus deodara</i> (D. Don) G. Don deodar cedar	300	8	225
<i>Cedrus libani</i> A. Richard cedar of Lebanon	200	11	305
<i>Celastrus scandens</i> L. American bittersweet	40	55	1,630
<i>Celastrus orbiculata</i> Thunberg oriental bittersweet	20	120	3,360
<i>Chamaecyparis lawsoniana</i> (A. Murray) Parlatore Port Orford cedar	5	465	13,100
<i>Chamaecyparis nootkatensis</i> (D. Don) Spach Alaska cedar	10	240	6,750
<i>Cupressus arizonica</i> Greene Arizona cypress	30	90	2,500
<i>Fraxinus americana</i> L. white ash	100	22	625
<i>Fraxinus excelsior</i> L. European ash	200	13	370

Table 1. Weights for working samples, TREE and SHRUB SEEDS (continued)

Kind of seed	Minimum weight for purity analysis <sup>a</sup>	Approximate number of seeds per gram <sup>b</sup>	Approximate number of seeds per ounce <sup>c</sup>
	Grams	Number	Number
<i>Fraxinus latifolia</i> Bentham			
Oregon ash	150	18	505
<i>Fraxinus nigra</i> Marshall			
black ash	100	25	710
<i>Fraxinus pennsylvanica</i> Marshall var. <i>subinterrima</i> (Vahl) Fernald			
green ash	100	25	710
<i>Fraxinus pennsylvanica</i> var. <i>lanceolata</i> (Borkh.) Sargent			
green ash	60	40	1,080
<i>Gleditsia triacanthos</i> L.			
honey locust	400	6	175
<i>Larix decidua</i> P. Miller			
European larch	15	170	4,810
<i>Larix eurolepis</i> A. Henry			
Dunkeld larch	10	240	6,750
<i>Larix kaempferi</i> (Lamarck) Carriere			
Japanese larch	10	260	7,380
<i>Larix occidentalis</i> Nuttall			
western larch	8	315	8,940
<i>Larix sibirica</i> (Muenchausen) Ledebour			
Siberian larch	25	95	2,690
<i>Liquidambar styraciflua</i> L.			
sweetgum	15	180	5,130
<i>Malus</i> spp.			
apple	50	45	1,250
<i>Malus</i> spp.			
crabapple	20	145	4,130
<i>Picea abies</i> (L.) Karsten			
Norway spruce	20	140	4,000
<i>Picea engelmannii</i> Engelmann			
engelmann spruce	8	300	8,440
<i>Picea glauca</i> (Moench) Voss			
white spruce	6	405	11,500
<i>Picea glauca</i> var. <i>albertiana</i> (S. Brown) Sargent			
western white spruce, Alberta white spruce	6	415	11,800
<i>Picea glauca</i> (Moench) Voss var. <i>glauca</i>			
Black Hills spruce	5	510	14,400
<i>Picea glehnii</i> (F. Schmidt) Masters			
Sakhalin spruce	8	300	8,520
<i>Picea jezoensis</i> (Sieb. & Zucc.) Carriere			
yeddo spruce	6	405	11,500
<i>Picea koyamai</i> Shirasawa			
Koyama spruce	8	310	8,770
<i>Picea mariana</i> (P. Miller) B.S.P.			
black spruce	3	890	25,300
<i>Picea omorika</i> (Pancic) Purkyne			
Serbian spruce	8	320	9,080



Table 1. Weights for working samples, TREE and SHRUB SEEDS (continued)

Kind of seed	Minimum weight for purity analysis <sup>a</sup>	Approximate number of seeds per gram <sup>b</sup>	Approximate number of seeds per ounce <sup>c</sup>
	Grams	Number	Number
<i>Picea orientalis</i> (L.) Link oriental spruce	15	175	4,780
<i>Picea polita</i> (Sieb. & Zucc.) Carriere tigertail spruce	40	65	1,810
<i>Picea pungens</i> Engelmann and var. <i>glauca</i> Beissner blue spruce and Colorado blue spruce	10	235	6,630
<i>Picea rubens</i> Sargent red spruce	8	310	8,750
<i>Picea sitchensis</i> (Bongard) Carriere sitka spruce	5	465	13,100
<i>Pinus albicaulis</i> Engelmann whitebark pine	300	8	225
<i>Pinus aristata</i> Engelmann bristlecone pine	50	50	1,440
<i>Pinus banksiana</i> Lambert jack pine	10	290	8,190
<i>Pinus cembra</i> L. Swiss stone pine	500	4	115
<i>Pinus cembroides</i> Zuccarini Mexican pinyon pine	500	4	115
<i>Pinus contorta</i> Loudon lodgepole pine (including var. <i>latifolia</i> )	10	225-300	6,400-8,440
<i>Pinus coulteri</i> D. Don coulter pine, bigcone pine	500	3	85
<i>Pinus densiflora</i> Siebold & Zuccarini Japanese red pine	25	100	2,810
<i>Pinus echinata</i> P. Miller shortleaf pine	25	105	3,000
<i>Pinus elliotii</i> Engelmann slash pine	70	30	905
<i>Pinus flexilis</i> James limber pine	250	10	275
<i>Pinus halepensis</i> P. Miller Aleppo pine	50	55	1,560
<i>Pinus heldreichii</i> Christ var. <i>leucodermis</i> (Antoine) Fitschen Bosnian pine	50	45	1,220
<i>Pinus jeffreyi</i> Greville & Balfour Jeffrey pine	300	7	200
<i>Pinus lambertiana</i> Douglas sugar pine	500	5	130
<i>Pinus monticola</i> D. Don western white pine	40	60	1,690
<i>Pinus mugo</i> Turra var. <i>mugo</i> Swiss mountain pine	20	135	3,880
<i>Pinus mugo</i> var. <i>mughus</i> (Scop.) Zenari mugo swiss mountain pine	15	180	5,150

Table 1. Weights for working samples, TREE and SHRUB SEEDS (continued)

Kind of seed	Minimum weight for purity analysis <sup>a</sup>	Approximate number of seeds per gram <sup>b</sup>	Approximate number of seeds per ounce <sup>c</sup>
	Grams	Number	Number
<i>Pinus nigra</i> Arnold			
Austrian pine	50	55	1,630
<i>Pinus nigra</i> Arnold var. <i>poiretiana</i> Schneider			
Corsican pine	30	70	2,010
<i>Pinus palustris</i> Miller			
longleaf pine	250	9	265
<i>Pinus parviflora</i> Siebbold & Zuccarini			
Japanese white pine	250	9	265
<i>Pinus ponderosa</i> P. & C. Lawson			
ponderosa pine, western yellow pine	90	25	750
<i>Pinus resinosa</i> Aiton			
red pine, Norway pine	20	115	3,260
<i>Pinus rigida</i> Miller			
pitch pine	20	135	3,880
<i>Pinus strobus</i> L.			
eastern white pine	40	60	1,690
<i>Pinus sylvestris</i> L.			
scotch pine	15	155	4,420
<i>Pinus taeda</i> L.			
loblolly pine	60	40	1,150
<i>Pinus thunbergii</i> Parlatore			
Japanese black pine	30	75	2,130
<i>Pinus virginiana</i> Miller			
Virginia pine, scrub pine	20	115	3,260
<i>Pinus wallichiana</i> A. B. Jackson			
Himalayan pine	125	20	570
<i>Prunus armeniaca</i> L.			
apricot	500	1	19
<i>Prunus avium</i> (L.) L.			
cherry	400	6	165
<i>Prunus domestica</i> L.			
plum (prune)	500	2	50
<i>Prunus persica</i> (L.) Batsch			
peach	1,500		7
<i>Pseudotsuga menziesii</i> (Mirbel) Franco			
grey douglas fir, var. <i>caesia</i> (Mirbel) Franco and			
blue douglas fir, var. <i>glauca</i> (Beissner) Franco	30	85	2,380
<i>Pseudotsuga menziesii</i> (Mirbel) Franco var. <i>menziesii</i>			
green douglas fir	25	95	2,630
<i>Pyrus communis</i> L.			
pear	70	35	940
<i>Robinia pseudoacacia</i> L.			
black locust	50	55	1,500
<i>Rosa multiflora</i> J. A. Murray			
multiflora rose	25	100	2,810
<i>Sequoia sempervirens</i> (D. Don) Endlicher			
redwood	12	210	5,950

Table 1. Weights for working samples, TREE and SHRUB SEEDS (continued)

Kind of seed	Minimum weight for purity analysis <sup>a</sup>	Approximate number of seeds per gram <sup>b</sup>	Approximate number of seeds per ounce <sup>c</sup>
	Grams	Number	Number
<i>Sequoiadendron giganteum</i> (Lindley) Buchholz			
giant sequoia	12	200	5,670
<i>Syringa vulgaris</i> L.			
common lilac	12	200	5,670
<i>Thuja occidentalis</i> L.			
northern white cedar, eastern arborvitae	3	765	21,600
<i>Thuja orientalis</i> L.			
Oriental arborvitae (Chinese arborvitae)	50	50	1,450
<i>Thuja plicata</i> D. Don			
western red cedar, giant arborvitae	3	915	25,900
<i>Tsuga canadensis</i> (L.) Carriere			
eastern hemlock, Canada hemlock	6	410	11,700
<i>Tsuga heterophylla</i> (Rafinesque) Sargent			
western hemlock, Pacific hemlock	4	655	18,600
<i>Ulmus americana</i> L.			
American elm	15	150	4,250
<i>Ulmus parvifolia</i> Jacquin			
Chinese elm	7	355	10,000
<i>Ulmus pumila</i> L.			
Siberian elm	15	145	4,060

<sup>a</sup>If it is necessary to conduct a noxious-weed seed determination, see section 2.3 for size of working sample. For peach, the 1,500 gram purity analysis may be considered the portion examined for noxious-weed seeds. In no other case does the amount examined for noxious-weed seeds need to exceed 500 grams.

<sup>b</sup>Figures in parentheses are the average number of seeds per gram to be used in computations of special tolerances. See Section 5.2c.

<sup>c</sup>The number of seeds per pound or the weight of 1,000 seeds can be calculated in the laboratory for individual lots from the sample submitted.

## 2.5 The purity analysis

a. *Separation of component parts.*—The working sample shall be weighed in grams to four significant figures and shall then be separated into four parts: (1) kind or cultivar to be considered pure seed; (2) other crop seed; (3) inert matter; and (4) weed seed. The four component parts shall be weighed in grams to the same number of decimal places as the working sample. The percentage of each part shall be determined to two decimal places.

b. *Calculation of percent of component parts in the sample.*

- (1) Minimum working sample less than 25 grams: Percentages shall be based on the sum of the weights of the component parts and not on the original weight. However, the sum of the weights of the component parts shall be compared with the original weight of the working sample as a check against loss of material or other error.



- (2) Minimum working sample of 25 grams or more: The other crop seed, inert matter, and weed seed shall be weighed and their percentages calculated on the basis of the original weight. The pure seed need not be weighed; its percentage may be determined by subtracting the sum of the percentages of the other three components from 100.

\* \* \* \*

**2.6 Seed unit.**—The seed unit is the structure usually regarded as a seed in planting practices and in commercial channels. \* \* \*

\* \* \* \*

**2.7 Kind or cultivar considered pure seed.**—The pure seed shall include all seeds of each kind and/or cultivar under consideration which are present in excess of 5% of the whole. Under certain circumstances kinds and/or cultivars present to the extent of 5% or less of the whole may be considered pure seed; for example, kinds or cultivars shown on a label as components of a mixture in amounts of 5% or less. The following shall be included with the pure seed:

- a. Immature or shriveled seeds and seeds that are cracked or otherwise damaged. This does not include seeds of legumes, crucifers, and conifers with the seed coats entirely removed. See section 2.10a(1).
- b. Pieces of broken and otherwise damaged seeds which are larger than one-half of the original size. \* \* \*
- c. Insect-damaged seeds, provided that the damage is entirely internal, or that the opening in the seed coat is not sufficiently large to allow the size of the remaining mass of tissue to be readily determined. \* \* \*
- d. Seeds that have started to germinate.

- \* \* \* \*
- h. Seed units with nematode galls, fungus bodies (i.e., ergot, smut, etc.) and spongy or corky caryopses which are entirely enclosed within the seed unit. \* \* \*

\* \* \* \*

**2.8 Other crop seed.**—Seeds of plants grown as crops (other than the kind or cultivar included in the pure seed) shall be considered other crop seeds, unless recognized as weed seeds by laws, regulations, or by general usage. All interpretations and definitions for *pure seed* in section 2.7 shall also apply in determining whether seeds are *other crop or inert matter*. \* \* \*

**2.9 Weed seed.**—Seeds, florets, bulblets, tubers, or sporocarps of plants recognized as weeds by laws, official regulations, or by general usage shall be considered weed seeds. \* \* \*

\* \* \* \*

**2.10 Inert matter.**—Inert matter shall include seeds and seedlike structures from both crop and weed plants and other materials not seed as follows:

- a. Seeds and seedlike structures from crop plants.
  - (1) Seeds of legumes, crucifers, and conifers with the seed coats entirely removed. Refer to section 2.7a.
  - (2) Pieces of broken and damaged seed units, including those that are insect damaged, which are half the original size or less; see section 2.7b and c. \* \* \*

- (5) Broken and unattached wings of tree and shrub seeds.
  - (6) Attached wings of tree and shrub seeds as follows:
    - (a) for *Cedrus*, *Picea*, *Tsuga*, and *Pinus* (except as noted below) the entire wing shall be detached and classed as inert matter;
    - (b) for *Abies*, *Larix*, *Libocedrus*, *Pseudotsuga*, *Pinus echinata*, *Pinus elliotii*, *Pinus palustris*, *Pinus rigida*, and *Pinus taeda* the wing shall be detached and removed as inert matter, except for that part which encloses the seed and is ordinarily not removed in seed conditioning;
    - (c) the seed wing shall not be removed as inert matter for *Acer*, *Betula*, *Catalpa*, *Chamaecyparis*, *Cupressus*, *Fraxinus*, *Liquidambar*, *Liriodendron*, *Platanus*, *Thuja*, and *Ulmus*.
  - (7) Seedlike structures from trees and shrubs consisting of wings with a thickened spot instead of a seed.
  - (8) Seed units with nematode galls or fungus bodies (smut, ergot, and other sclerotia) which are not entirely enclosed within the seed unit. \* \* \*
- \* \* \*
- b. Seeds and seedlike structures from weed plants \* \* \*
- \* \* \*
- c. Other non-seed matter.
    - (1) Free nematode galls or fungus bodies such as smut, ergot and other sclerotia.
    - (2) Soil particles, sand, stones, chaff, stems, leaves, flowers, cone scales, pieces of bark, pieces of resin, etc.
- \* \* \*

## 4. GERMINATION TESTS

### 4.1 Source of seeds for germination

- a. *When both purity and germination tests are required.*—Seeds for germination shall be taken from the separation of the kind or cultivar considered pure seed and shall be counted without discrimination as to size or appearance.
- b. *When only a germination test is required.*—If only a germination test is required and the pure seed is determined or estimated to be at least 98 percent, the pure seed for the germination test may be taken indiscriminately from a representative portion of the bulk.

If the pure seed is found to be less than 98 percent the seed for the test shall be obtained by separating the sample into two components as follows: (a) pure seed and (b) other crop seed, weed seed, and inert matter. In making this separation at least ¼ of the quantity required for a regular purity analysis shall be used. If the reduced amount is used the sample must be well mixed and divided so that the subsample obtained will be representative of the sample.

### 4.2 Definitions

- a. *Seed germination.*—In seed laboratory practice, germination is defined as the emergence and development from the seed embryo of those essential structures which, for the kind of seed in question, are indicative of the ability to produce a normal plant under favorable conditions. Refer to 4.2d and e.
- b. *Normal seedlings.*—Seedlings possessing the essential structures that are indicative of their ability to produce plants under favorable conditions.
- c. *Abnormal seedlings.*—All seedlings that can not be classified as normal seedlings.

- d. *Hard seeds*.—Seeds which remain hard at the end of the prescribed test period because they have not absorbed water due to an impermeable seed coat. Seeds known and recognized to contain hard seed are indicated by footnotes in Table \* \* \* 5. The percentage hard seed is to be reported in addition to the percentage germination.
- e. *Dormant seed*.—Viable seeds, other than hard seeds, which fail to germinate when provided the specified germination conditions for the kind of seed in question. Viability of ungerminated seeds may be determined by any appropriate method or combination of methods, such as a cutting test, tetrazolium test, scarification, and application of germination promoting chemicals. \* \* \*
- f. *Prechill*.—Place the seed on or in moist substrata at the indicated low temperature for the specified period of time. Tree and shrub seeds may be prechilled whenever it is deemed necessary.

Procedures for tree and shrub seed prechill:

- (1) Place seed in closed dish on moist substratum.
  - (2) Place seed in a loosely woven bag or screen and insert in a moisture holding medium such as peat, sand, or vermiculite.
  - (3) Soak seed for 24 hours in tap water at room temperature (18-22° C), drain excess water and place in a suitable capped glass or plastic vial, or polyethylene bag.
- g. *Predry*.—Place the seed in a shallow layer at a temperature of 35° C to 40° C for a period of 5 to 7 days, with provision for circulation of the air.

- 4.3 Moisture and aeration.**—The substratum must be moist enough to supply the needed moisture to the seeds at all times. Avoid supplying excessive moisture which will restrict aeration of the seeds. Except as provided for those kinds of seeds requiring high moisture levels in the germination media, the substrata should never be so wet that a film of water is formed around the seeds. For most kinds of seeds, blotters or other paper substrata should not be so wet that by pressing, a film of water forms around the finger. See section 4.9-b.

The addition of water subsequent to placing the seeds in test will depend on the evaporation from the substrata in the germination chambers. Since the rate of evaporation will depend upon the relative humidity of the air, it is desirable to keep water in the germination chambers or to provide other means of supplying a relative humidity of approximately 95 percent. Germination tests should be inspected at frequent intervals to insure that an adequate moisture supply is available at all times.

\* \* \* \* \*

- 4.4 Number of seeds for germination.**—At least 400 seeds shall be tested for germination except that in mixtures 200 seeds of those kinds present to the extent of 15 percent or less may be used. In this case an additional 2 percent is to be added to the regular germination tolerances. These seeds shall be tested in replicate tests of 100 seeds or less to avoid crowding on the substratum.

#### **4.5 Evaluation of seedlings**

- a. *Seedlings infected with fungi or bacteria*.—Such seedlings shall be regarded as normal if they are otherwise normal. A seedling that has been seriously damaged by bacteria or fungi from any source other than the specific seed shall be regarded as normal if it is determined that all essential structures are present.

Germination counts should be made on samples where contamination and decay are present at approximately 2-day intervals between the usual first count and the final count. During the progress of the germination test, seeds which are obviously dead and moldy and which may be a source of contamination of healthy seeds should be



removed at each count and the number of such dead seeds should be recorded. When symptoms of certain diseases develop which can be readily recognized and identified, their presence should be reported.

If a chemical preparation is used to reduce the spread of micro-organisms, the results, should be regarded as supplemental information and reported as such.

b. *Guides for evaluation of seedling.*

- (1) Sand and/or soil tests. Such tests shall be considered the guide in determining the classification of questionable seedlings grown on approved artificial media when there is doubt as to the proper evaluation of the seedlings.

\* \* \* \* \*

#### 4.7 Calculation of percentage germination

- a. *When a single test is made* in accordance with these rules and retesting is not required, the average of the four, three, or two 100-seed replicates shall be reported as the percentage germination or germination and hard seeds.

\* \* \* \* \*

#### 4.9 Explanation of Tables 3, 4, and 5

Tables 3, 4, and 5 contain specific germination requirements for the kinds of seeds listed in column 1. Some explanations of these tables and additional germination requirements and conditions are as follows:

- a. *Substrata*.—Symbols for substrata in column 2, Tables 3 and 4 are: B = between blotters; TB = top of blotters; T = paper toweling, used either as folded towel tests or as roll towel tests in horizontal or vertical position; S = sand or soil; TS = top of sand or soil; P = covered petri dishes with (a) two layers of blotters, or (b) three thicknesses of filter paper, or (c) top of sand or soil; C = creped cellulose paper wadding (0.3-inch thick Kimpak or equivalent) covered with a single thickness of blotter through which holes are punched for the seed which are pressed for about one-half their thickness into the paper wadding; RB = blotters with raised covers, prepared by folding up the edges of the blotter to form a good support for the upper fold which serves as a cover, preventing the top from making direct contact with the seeds; TC = on top of creped cellulose paper without a blotter.

Symbols for substrata in column 2, Table 5, are the same as for Tables 3 and 4 except that "P" includes (in addition to the above indicated materials) sponge rock, vermiculite, terralite, or a mixture of 50% sand and vermiculite, sand and perlite, etc. If there is question as to whether a paper substratum is toxic to developing seedlings, check tests should be made on Whatman's No. 2 filter paper or its equivalent. Seeds of celery, celeriac, chicory, dandelion, timothy, and Bermudagrass are particularly sensitive to toxic substrata. If root injury is evident on substratum moistened with potassium nitrate, retests should be made on substratum moistened with water.

- b. *Moisture*.—The directions and suggestions given under the heading "*Moisture and Aeration*" section 4.3 should be observed. \* \* \*
- c. *Temperature*.—Single numerals in the Tables indicate constant temperatures. Two numerals separated by a dash indicate an alternation of temperature, the test to be held at the first temperature for approximately 16 hours and at the second temperature for approximately 8 hours per day. If the tests are not subjected to alternating temperatures over weekends and on holidays, they are to be held at the lower temperature during this time. In the case of species of *Trifolium*, *Medicago* and *Vicia faba*, the temperature should not exceed 20° C and a temperature of 17° to 18° C is more desirable. A sharp alternation of temperature, such as obtained by hand transfer, may be beneficial in breaking dormancy.

d. *Duration of test.*—The duration of test for each of the various kinds of seeds is given in Tables 3, 4, and 5. The following deviations from the prescribed test are permitted:

- (1) The prechilling period is not included in the germination periods given in Tables 3, 4, and 5 unless otherwise specified.
- (2) The number of days stated for the first count is approximate and a deviation of one to three days is permitted.
- (3) Any test may be terminated prior to the number of days listed under "Final Count" if the analyst is positive the maximum germination of the sample has been attained.
- (4) If at the end of the prescribed test period, the seedlings are not sufficiently developed for positive evaluation, the test may be extended two more days.
- (5) If any test indicates low vitality, this fact should be reported.

\* \* \* \* \*

In tests of tree and shrub seed, seed remaining at the end of the test should be cut and examined for any fresh, firm, possibly viable seed which may have potential planting value. A retest of prechilled seed may be advisable when an extremely high percent of firm, fresh seed is found.

e. *Light.*—Where light is prescribed in Tables 3, 4, and 5, it should be provided by a cool white fluorescent source. The illuminance for dormant seed should be 75-125 ft-c (750-1250 lux). The seeds should be illuminated for at least 8 hours in every 24. Where the seeds are germinated at alternating temperatures they should be illuminated during the high temperature period. \* \* \* seeds for which light is prescribed should be germinated on top of the substratum. \* \* \*

For tree and shrub seed, an intensity of at least 50 ft-c, and preferably 75-100 ft-c, should be provided. Up to 16 hours of light may be beneficial to some kinds and certain lots of other kinds, as noted in Table 5.

f. *Potassium nitrate.*—A two-tenths (0.2) percent solution of potassium nitrate ( $\text{KNO}_3$ ) is used in moistening the substratum and is prepared by dissolving 2 grams of  $\text{KNO}_3$  in 1000 ml of distilled water. The grade of the potassium nitrate shall meet A.C.S. specifications.

\* \* \* \* \*

1.12, Table 5. Methods of testing for laboratory germination, TREE and SHRUB SEEDS

Kind of seed	Substrata	Temperature °C	Test duration days	Additional Directions
<i>Abies amabilis</i> Pacific silver fir	P	15-25	28	Light; prechill 0-5° C 14 days. Light; some sources may need prechill 21 days at 3-5° C.
<i>Abies balsamea</i> balsam fir	TB, P	20-30	21	Light; prechill 28 days at 3-5° C.
<i>Abies concolor</i> white fir	TB, P	20-30	28	Light; many lots complete in 14-21 days. A few sources from the Pacific coast region may need prechill for 3 weeks at 3-5° C.
<i>Abies fraseri</i> fraser fir	TB, P	20-30	21	Light; prechill 28 days at 3-5° C.
<i>Abies grandis</i> grand fir	TB, P	20-30	28	Light; prechill 14 days at 3-5° C. Vermiculite (P) is satisfactory. Dark; prechill 21 days at 3-5° C.
<i>Abies homolepis</i> nikko fir	TB, P	20-30	21	Light; prechill 21 days at 3-5° C.
<i>Abies lasiocarpa</i> subalpine fir	TB, P	20-30	28	Light.
<i>Abies magnifica</i> California red fir and shasta red fir	TB, P	20-30	21	Prechill 28 days at 3-5° C.
<i>Abies procera</i> noble fir	TB, P	20-30	28	Light; prechill 14 days at 3-5° C. Vermiculite is recommended if TB is not used. Dark; prechill 21 days at 3-5° C.
<i>Abies veitchii</i> veitch fir	TB, P	20-30	28	Light.
<i>Acer</i> spp. (See Purity Table 1). maples, boxelder	P	18 to 22	14	Use embryo excision method <sup>a</sup> . Prechill 2 months 3-5° C. It is an advantage to remove the pericarp before testing.
<i>Aesculus pavia</i> L. red buckeye	TC	20-30	28	
<i>Ailanthus altissima</i> tree of heaven, ailanthus	TB	20-30	21	
<i>Berberis thunbergii</i> Japanese barberry	P	18-22	10-14	Use embryo excision method <sup>a</sup> .
<i>Berberis vulgaris</i> European barberry	P	18-22	10-14	Use embryo excision method <sup>a</sup> .
<i>Betula</i> spp. (See Purity Table 1). birches	P	20-30	21	Light.
<i>Carya illinoensis</i> (Wangenheim) K. Koch pecan	TC	20-30	28	Prechill 60 days at 3-5° C.
<i>Carya ovata</i> (Miller) K. Koch shagbark hickory	TC	20-30	28	Prechill 60 days at 3-5° C.
<i>Dasuarina</i> spp. beefwood	C, TB	20-30	14	Light.
<i>Datalpa bignonioides</i> southern catalpa	TB	20-30	21	
<i>Datalpa speciosa</i> northern catalpa	TB	20-30	21	
<i>Cedrus</i> spp. (See Purity Table 1). cedars	TB	20	21	Prechill 14 days at 3-5° C.



Table 5. Methods of testing for laboratory germination, TREE and SHRUB SEEDS (continued)

Kind of seed	Substrata	Temperature °C	Test duration days	Additional Directions
<i>Celastrus</i> spp. (See Purity Table 1). bittersweet	P	18-22	10-14	Use embryo excision method <sup>a</sup> .
<i>Chamaecyparis</i> spp. (See Purity Table 1). cedars, falsecypress	TB, P	20	28	Use KNO <sub>3</sub> if dormant.
<i>Cornus florida</i> L. flowering dogwood	C, TB P	20-30 18-22	28 10	Prechill 90 to 120 days at 3-5° C. Embryo ex- cision.
<i>Cornus stolonifera</i> Michaux red-osier dogwood	P	18-22	10	Prechill 90 days at 3-5° C. Embryo excision.
<i>Crataegus mollis</i> Scheele downy hawthorn	C, TB	20-30	14	2 hrs. H <sub>2</sub> SO <sub>4</sub> , followed by 90 days prechill at 20° C then 120 days at 3-5° C. TZ <sup>b</sup> may also be used.
<i>Cupressus arizonica</i> Arizona cypress	TB	20-30	28	Light; some lots need 20 days prechill.
<i>Eucalyptus deglupta</i> Blume	C, TB	20-30	14	
<i>Eucalyptus grandis</i> Sieber ex Benth	C, TB	25	14	Light.
<i>Fraxinus</i> spp. (See Purity Table 1). ash	P	18-22	10-14	Use embryo excision method <sup>a</sup> . TZ <sup>b</sup> may also be used. Prechill 3-5° C in moist substratum 3 months.
<i>Gleditsia triacanthos</i> L. honey locust	B	20	21	See footnote <sup>c</sup> .
<i>Grevillea robusta</i> silk-oak	C, TB	20-30	21	Light.
<i>Larix decidua</i> European larch	TB, P	20-30	21	Light.
<i>Larix eurolepis</i> Dunkeld larch	TB, P	20-30	21	Light.
<i>Larix kaempferi</i> Japanese larch	TB, P	20-30	16	Light; prechill 21 days at 3-5° C.
<i>Larix occidentalis</i> western larch	TB, P	20-30	21	Light; if dormant, prechill or use KNO <sub>3</sub> .
<i>Larix sibirica</i> Siberian larch	TB, P	20-30	21	Light.
<i>Libocedrus decurrens</i> incense-cedar	C, TB	20-30	28	Prechill 30 days at 3-5° C.
<i>Liquidambar styraciflua</i> sweetgum, red gum	TB	20-30	28	Light; sensitive to drying in test.
<i>Liriodendron tulipifera</i> L. yellow-poplar	C, TB	20-30	28	Prechill 60 days at 3-5° C; or use TZ or em- bryo excision.
<i>Magnolia grandiflora</i> L. southern magnolia	C, TB	20-30	42	Prechill 45 days at 3-5° C; or use TZ.
<i>Malus</i> spp. apple, crabapple	P	18-22	7-10	Use embryo excision method <sup>a</sup> . TZ <sup>b</sup> may also be used.
<i>Nyssa aquatica</i> L. water tupelo	TC	20-30	21	Prechill 30 days at 3-5° C.
<i>Nyssa sylvatica</i> Marshall black tupelo	C, TB	20-30	28	Prechill 21 days; very few lots dormant.
<i>Picea abies</i> Norway spruce	TB	20-30	16	20° C and 25° C temperatures are also satisfactory.
<i>Picea engelmannii</i> engelmann spruce	TB, P	20-30	16	Light; sensitive to excessive moisture; use KNO <sub>3</sub> if dormant.
<i>Picea glauca</i> white spruce	TB	20-30	21	Light; some Canadian seed sources require prechill for 14-21 days at 3-5° C.
<i>Picea glauca</i> var. <i>albertiana</i> western white spruce, Alberta white spruce	TB	20-30	21	Light.

Table 5. Methods of testing for laboratory germination, TREE and SHRUB SEEDS (continued)

Kind of seed	Substrata	Temperature °C	Test duration days	Additional Directions
<i>Picea glauca</i> var. <i>glauca</i> Black Hills spruce	TB	20-30	21	Light.
<i>Picea glehnii</i> sakhalin spruce	TB, P	20-30	14	Prechill 21 days at 3-5° C.
<i>Picea jezoensis</i> yeddo spruce	TB, P	20-30	14	Prechill 21 days at 3-5° C.
<i>Picea koyamai</i> Koyama spruce	TB	20-30	21	Light.
<i>Picea mariana</i> black spruce	TB	20-30	16	Light.
<i>Picea omorika</i> Serbian spruce	TB	20-30	16	Light.
<i>Picea orientalis</i> oriental spruce	TB	20-30	21	Light.
<i>Picea polita</i> tigertail spruce	TB	20	21	
<i>Picea pungens</i> vars. blue spruce and Colorado blue spruce	TB, P	20-30	16	20° C and 25° C temperatures are also satisfactory.
<i>Picea rubens</i> red spruce	TB	20-30	28	Light.
<i>Picea sitchensis</i> sitka spruce	TB, P	20-30	21	Light; more than 8 hr light may be beneficial to some lots; if dormant add KNO <sub>3</sub> .
<i>Pinus albicaulis</i> whitebark pine	P TB, P	18 to 22 20-30	10-14 28	Use embryo excision method <sup>a</sup> . Light; prechill 28 days at 3-5° C.
<i>Pinus aristata</i> bristlecone pine	TB, P	20-30	14	
<i>Pinus banksiana</i> jack pine	TB, P	20-30	14	Light.
<i>Pinus canariensis</i> C. Smith canary pine	P	20	21	Light; sensitive to warm temperatures; 1-day soak prior to test helpful.
<i>Pinus caribaea</i> Morelet caribbean pine	C, TB	20-30	21	
<i>Pinus cembra</i> Swiss stone pine	P S, P	18 to 22 20-30	10-14 28	Use embryo excision method <sup>a</sup> . TZ <sup>b</sup> may also be used. Prechill 6-9 months at 3-5° C.
<i>Pinus cembroides</i> Mexican pinyon pine	B, P	20	28	Use embryo excision method <sup>a</sup> for dormant lots.
<i>Pinus clausa</i> (Chapman) Vasey sand pine	TB	22	21	Sensitive to excess moisture
<i>Pinus contorta</i> lodgepole pine, shore pine	TB, P	20-30	28	Light; more than 8 hr light may be beneficial to some lots. Prechill 28 days at 3-5° C
<i>Pinus contorta</i> var. <i>latifolia</i> lodgepole pine	TB, P	20-30	21	Light; prechill 28 days at 3-5° C.
<i>Pinus coulteri</i> coulter pine, bigcone pine	P S, P	18 to 22 15-25	10-14 28	Use embryo excision method <sup>a</sup> . Prechill for 8 or 12 weeks at 3-5° C.
<i>Pinus densiflora</i> Japanese red pine	TB, P	20-30	21	Light.
<i>Pinus echinata</i> shortleaf pine	TB, P P	20-30 22	28 28	Light; 8 hr light may be beneficial to some lots; sensitive to drying. No prechill, and prechill 28 days at 3-5° C 16 hr light (both methods each sample).
<i>Pinus elliotii</i> slash pine	TB, P P	20-30 22	28 28	Light; 8 hr light may be beneficial to some lots; sensitive to drying. Light; no prechill, and prechill 28 days at 3-5° C (both methods each sample).

Table 5. Methods of testing for laboratory germination, TREE and SHRUB SEEDS (continued)

Kind of seed	Substrata	Temperature °C	Test duration days	Additional Directions
<i>Pinus flexilis</i> limber pine	B, P	20-30	21	Prechill 21 days at 3-5° C.
<i>Pinus glabra</i> Walters spruce pine	TB, P	20-30	16	Light; prechill 21 days at 3-5° C.
<i>Pinus halepensis</i> Aleppo pine	TB, P	20	28	Sensitive to warm temperature.
<i>Pinus heldreichii</i> var. <i>leucodermis</i> bosnian pine	TB, P	20-30	28	Light; prechill 40 days at 3-5° C.
<i>Pinus jeffreyi</i> jeffrey pine	TB, P S, P	20-30 20-30	21 21	Light; embryo excision method applicable to dormant lots. Prechill for 4 or 8 weeks at 3-5° C.
<i>Pinus khasya</i> Engelmann khasia pine	TB	20-30	21	Light.
<i>Pinus lambertiana</i> sugar pine	P S, P	18 to 22 20-30	10-14 28	Use embryo excision method <sup>a</sup> . Prechill 8 or 12 weeks at 3-5° C.
<i>Pinus luchuensis</i> Mayr Formosa pine	TB	20-30	21	Light.
<i>Pinus merkusii</i> Junghuhn & DeVriese merkus pine	TB	20-30	21	Light.
<i>Pinus monticola</i> western white pine	P S, P	18 to 22 20-30	10-14 28	Use embryo excision method <sup>a</sup> . Prechill 8 to 12 weeks at 3-5° C.
<i>Pinus mugo</i> vars. Swiss mountain pine, Mugo Swiss mountain pine	TB, P	20-30	14	Light.
<i>Pinus muricata</i> bishop pine	TB	20-30	21	Light.
<i>Pinus nigra</i> Austrian pine	TB, P	20-30	14	Light.
<i>Pinus nigra</i> var. <i>poiretiana</i> Corsican pine	TB, P	20-30	14	Light
<i>Pinus palustris</i> longleaf pine	P	20	21	8 hr light.
<i>Pinus parviflora</i> Siebold & Zuccarini Japanese white pine	P	18 to 22	10-14	Use embryo excision method <sup>a</sup> .
<i>Pinus patula</i> Schiede & Deppe Jelecote pine	TB, P	20	18	Light; sensitive to temperature.
<i>Pinus pinaster</i> Aiton cluster pine	TB, P	20	28	Light; sensitive to temperature and possibly moisture; some seed sources need prechill.
<i>Pinus pinea</i> L. Italian stone pine	P	20	21	Light; soak 1 day prior to test; some lots sensitive to warm temperatures.
<i>Pinus ponderosa</i> ponderosa pine, western yellow pine	TB, P	20-30	21	Light; prechill 28 days at 3-5° C.
<i>Pinus radiata</i> monterey pine	P	20	25	Light; more than 8 hr may be beneficial; prefers good moisture supply; prechill 21 days at 3-5° C.
<i>Pinus resinosa</i> red pine, Norway pine	TB, P	20-30; 25	14	Light not essential for maximum germination.
<i>Pinus rigida</i> pitch pine	TB, P	20-30	14	Light.
<i>Pinus serotina</i> Michaux pond pine	TB	22	21	



Table 5. Methods of testing for laboratory germination, TREE and SHRUB SEEDS (continued)

Kind of seed	Substrata	Temperature °C	Test duration days	Additional Directions
<i>Pinus strobus</i> eastern white pine	TB, P	20-30	21	Light; more than 8 hr. light may be beneficial to some lots; sensitive to drying; prechill 28-42 days at 3-5° C.
	P	22	28	Light for 16 hr.; prechill 28-42 days at 3-5° C.
<i>Pinus sylvestris</i> scotch pine	TB, P	20-30	14	Light; seed from eastern Mediterranean (Turkey, Greece, Bulgaria) provinces may require prechill 21 days at 3-5° C.
<i>Pinus taeda</i> loblolly pine	TB, P	30-30	28	Light; more than 8 hr light may be beneficial to some lots; sensitive to drying.
	P	22	28	No prechill, and prechill 28 days at 3-5° C. 16 hr light (both methods each sample).
<i>Pinus thunbergii</i> Japanese black pine	TB, P	20-30	21	Light; more than 8 hr light may be beneficial to some lots.
<i>Pinus virginiana</i> Virginia Pine scrub pine	TB, P	22	21	16 hr light
	TB	20-30	21	Light; 8 hr light may be beneficial to some lots
<i>Pinus wallichiana</i> Himalayan pine	TB, P	20-30	28	Light; more than 8 hr light may be beneficial to some lots.
<i>Platanus occidentalis</i> L. American sycamore	TB	20-30	14	
<i>Populus</i> spp. poplar	20-30	14		Light.
<i>Prunus</i> spp. (See Purity Table 1). apricot, cherry, peach, plum	P	18 to 22	10-14	Use embryo excision method. <sup>a</sup> TZ <sup>b</sup> may also be used.
<i>Pseudotsuga menziesii</i> var. <i>caesia</i> grey douglas fir	TB, P	20-30	21	Light; prechill 21 days at 3-5° C. Vermiculite recommended if TB not used.
<i>Pseudotsuga menziesii</i> var. <i>glauca</i> blue douglas fir	TB, P	20-30	21	Light; central and southern Rocky Mountain sources not sensitive to temperature. Vermiculite recommended if TB not used.
<i>Pseudotsuga menziesii</i> var. <i>menziesii</i> green douglas fir	TB, P	20-30	21	Light; prechill 21 days at 3-5° C. Vermiculite or Perlite (sponge rock) recommended if TB not used.
<i>Pyrus communis</i> L. (See Purity Table 1). pear	P	18 to 22	10-14	Use embryo excision method <sup>a</sup> TZ <sup>b</sup> may also be used.
<i>Quercus</i> spp. (red or black oak group)	TC, TB	20-30	14	Cut 1/3 off cup scar end of acorn and remove pericarp.
<i>Quercus alba</i> L. white oak	TC	20-30	28	
<i>Quercus muehlenbergii</i> Engelman chinkapin oak	TC	20-30	28	
<i>Quercus virginiana</i> Miller live oak	TC	20-30	28	
<i>Rhododendron</i> spp. <i>rhododendron</i>	C, TB	20-30;25	21	Light.
<i>Robinia pseudoacacia</i> black locust	B	20	21	See footnote <sup>c</sup> .
<i>Rosa multiflora</i> multiflora rose	TB, P	10-30	28	Light; prechill 28 days at 3-5° C. TZ <sup>b</sup> may also be used.
<i>Sequoia sempervirens</i> redwood	TB, P	20-30	21	Light.

Table 5. Methods of testing for laboratory germination, TREE and SHRUB SEEDS (continued)

Kind of seed	Substrata	Temperature °C	Test duration days	Additional Directions
<i>Sequoiadendron giganteum</i> giant sequoia	TB, P	20-30	28	Light; sensitive to drying; may prechill 30 days.
<i>Syringa vulgaris</i> common lilac	TB	20	21	
<i>Thuja occidentalis</i> northern white cedar, eastern arborvitae	TB, P	20-30	21	Light.
<i>Thuja orientalis</i> oriental arborvitae, Chinese arborvitae	TB, P	20	21	
<i>Thuja plicata</i> western red cedar, giant arborvitae	TB, P	20-30	21	Light; use KNO <sub>3</sub> if dormant.
<i>Tsuga canadensis</i> eastern hemlock, Canada hemlock	TB, P	15	28	Light; prechill 28 days at 3-5° C.
<i>Tsuga heterophylla</i> western hemlock, Pacific hemlock	TB, P	20	28	Light.
<i>Ulmus americana</i> American elm	TB	20-30	14	Light.
<i>Ulmus parvifolia</i> Chinese elm	TB	20	10	
<i>Ulmus pumila</i> Siberian elm	TB	20	10	
<i>Vitis vulpina</i> L. riverbank grape	C, TB	20-30	28	Prechill 90 days at 3-5° C; or use TZ.

<sup>a</sup>Embryo excision method: Embryo excision tests can be placed at the temperatures indicated or at ordinary room temperatures if the maximum temperature does not exceed 24° C constantly. Details and literature concerning this method are given in the article: "The excised embryo method for testing germination of dormant seed," Proc. Assoc. Offic. Seed Anal. 45:108-117. 1955 Results are to be reported as percentage viability, as determined by an embryo excision test.

<sup>b</sup>T.Z. Tetrazolium: For procedure see the 1959 International Seed Testing Association Rules and amendments of May 12, 1962, Section 6.0, "Biochemical Tests for Viability." Results are to be reported as percentage viability, as determined by a tetrazolium test.

<sup>c</sup>Hard seed often present; see sections 4.2-d and 4.9-e. The viability of these hard seeds may be determined by clipping or filing the testa, or by a concentrated H<sub>2</sub>SO<sub>4</sub> soak for approximately 1 hour followed by washing, and then returning them to test conditions.

\* \* \* \* \*

## 5. TOLERANCES

\* \* \* \* \*

### 5.5 Germination

The following tolerances are applicable to the percentages of germination and also to the sum of the germination plus the hard seed when 400 or more seeds are tested:

Mean	Tolerance	Mean	Tolerance
96 or over .....	5	70 or over but less than 80 .....	8
90 or over but less than 96 .....	6	60 or over but less than 70 .....	9
80 or over but less than 90 .....	7	Less than 60 .....	10

When only 200 seeds of mixtures are tested, 2% shall be added to the above germination tolerances.

\* \* \* \* \*

## APPENDIX I. SEEDLING DESCRIPTIONS

These seedling descriptions are a part of the Rules for Testing Seeds as set forth in section 4.5. \* \* \*

For general instructions on evaluation of seedlings infected with fungi or bacteria see section 4.5 of these rules.

Seedlings difficult or impossible to evaluate because of injury due to chemical treatment of the seeds, exposure to chemicals, or toxicity from germinator trays may be retested in soil or a mixture of soil and sand and the result of this test should be reported \* \* \*.

In general, the following anatomical parts, free from decay, should be present in normal seedling: a well-developed primary root system; a well-developed intact hypocotyl and/or epicotyl; an intact plumule in the Poaceae and an intact terminal growing point in other groups; one cotyledon in monocots and two cotyledons in dicots.

\* \* \* \* \*

### 12. Trees and shrubs

#### Normal seedling

- (a) Seedling possessing those essential structures that are indicative of its ability to produce a plant under favorable conditions.

#### Abnormal seedling

- (a) Weak, rootless or broken.
- (b) With poor or stunted radicle growth.
- (c) With radicle emerging from the seed coat with apparently normal development of hypocotyl and cotyledons, but radicle failing to develop.
- (d) With radicle emerging from the seed coat but growing horizontally or upward.
- (e) With radicle emerging from the seed coat but being destroyed by rapid growth of fungus from within the seed coat.
- (f) With cotyledons emerging from the seed coat before the radicle.
- (g) Seed split from internal growth with nothing emerging or with only short blunt extension of endosperm and radicle.
- (h) With stunted hypocotyl carrying a "collar" of endosperm tissue.
- (i) With double embryos fused together. (If two seedlings emerge from a seed and they are not fused, or one is normal or produces a completely normal plant, the unit would not be classed as abnormal).
- (j) Without pigment — albino.
- (k) Watery — Translucent in appearance.





**Stein, William I.; Danielson, Rodger; Shaw, Nancy; Wolff, Scott; Gerdes, David.** Users guide for seeds of western trees and shrubs. Gen. Tech. Rep. PNW-193. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 45 p.

Because the role of tree and shrub seed is indispensable in the renewal of forests and ranges, their identity and quality are critically important. This guide briefly covers recommended practices for maintaining the identity of seeds, for sampling them, and for testing them for quality. Practices associated with the testing and use of tree seed have developed over many years, whereas those for shrub seed are just developing. Selected references, excerpts from official seed testing rules, addresses of seed testing laboratories, and sources of information for shrub seed are included.

Keywords: Seed (tree), seed (shrub), seed testing, seed quality.

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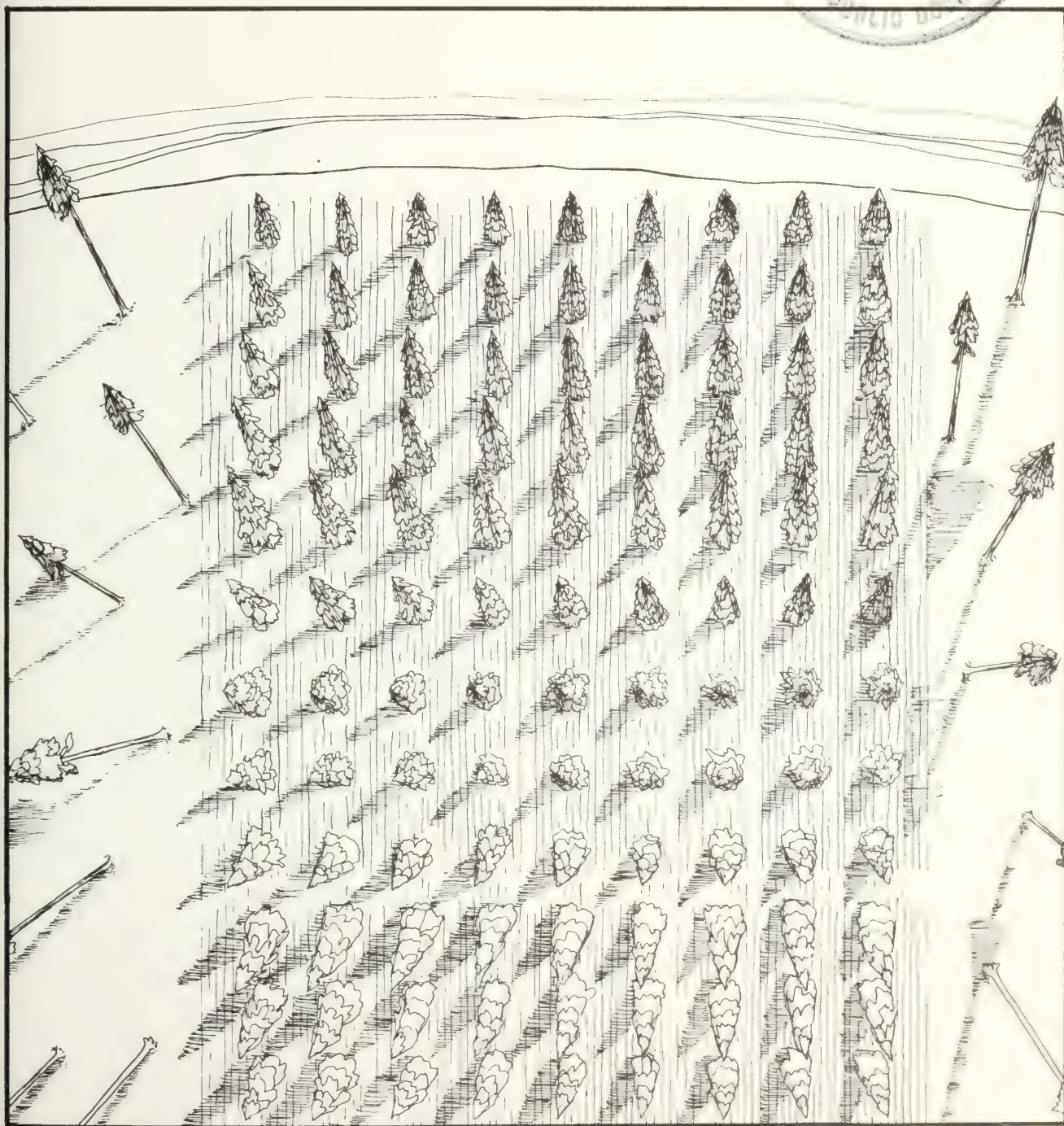
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# The Yield Advantages of Artificial Regeneration at High Latitudes



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AT HIGH LATITUDES

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## FOREWORD

Edmond C. Packee

The Sixth International Workshop on Forest Regeneration at High Latitudes took place during a period of transition for the forest industry worldwide. The economic slump in the forest products industry had bottomed-out; the planting approach to forest regeneration was being questioned, primarily, but not solely for economic reasons; the future of the workshops on Forest Regeneration at high latitudes was being examined; and changes were in progress within the School of Agriculture and Land Resources Management at the University of Alaska-Fairbanks.

The economic slump in the forest industry began in North America in 1981. The profits of the previous decade evaporated overnight. The concept of sustained yield forest management was being challenged for economic reasons. In the North American west and north, funds simply are not available for long-term investment in forest stand management. Tree planting, one of the more expensive long-term forestry investments, is being scrutinized more closely. Alternatives, including planting of seeds instead of seedlings, encouragement and acceptance of natural regeneration, accepting longer regeneration periods, and even accepting non-satisfactory levels of stock, are being considered.

Hence, the workshop on "The Yield Advantages of Artificial Regeneration" was most timely. The

Workshop group approached this issue from two directions possibly the most important was a field tour of industrial forest lands to observe and assess operational plantations and natural stands. J.D. Irving Ltd. provided access to their operation near St. Leonard, New Brunswick. Their intensively managed forest contains some of the most extensive acreage of spruce plantations in eastern Canada as well as examples of natural stands. The presentation of formal papers addressed the advantages of artificial regeneration and ways of economic evaluation. From both the field observations and the formal papers, artificial regenerations, although fraught with problems, has yield advantages across a large range of sites under a broad range of conditions.

This was the sixth international workshop focusing on forest regeneration at high latitudes. Workshop locations and topics, past and planned are listed on the following page.

The School of Agriculture and Land Resources Management of the University of Alaska-Fairbanks initiated this series of workshops in 1979. However, if it were not for the many cooperators, the workshops would not have succeeded.

Because of the circumpolar interest involving three continents and the international effort, association with an internationally recognized organization was deemed desirable. At the Edmundston, New Brunswick workshop, the group decided to seek IUFRO (International Union of Forest Research Organizations) affiliation. In January 1985 IUFRO affiliation was obtained within Division 1; the group was recognized as Working Party S1.05-12, "Silvi-

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<u>Year</u>	<u>Location</u>	<u>Topic</u>
1979	Fairbanks, Alaska, U.S.A	General problems related to forest regeneration in the circumpolar north.
1980	Umea, Sweden	Forest regeneration problems in Sweden.
1981	Prince George, British Columbia, Canada	Forest regeneration problems in north- west Canada.
1982	Hinton, Alberta, Canada	Management of lodge- pole pine in the boreal forest.
1983	Fairbanks, Alaska, U.S.A	Forest classification at high latitudes as an aid to forest regeneration.
1984	Edmundston, New Brunswick, Canada	The yield advantages of artificial regeneration of High Latitudes.
1985	Lulea, Sweden	Forest regeneration at northern latitudes close to timber line.
1986	Ft. St. John, British Columbia, Canada	To be announced.
1987	Finland (tentative)	To be announced.

culture and Management of Northern Forests." Hence the workshop to be held in June 1985 in Umea, Sweden will be the first as a IUFRO organization.

Finally, there have been changes at the School of Agriculture and Land Resources Management of the University of Alaska. Mr. Anthony F. Gasbarro's responsibilities as Extension Forester have increased. "Tony", as we all know him, was the prime organizer of the first five workshops and was the individual who held the group together. He is to be applauded for his efforts. In 1983, I joined the Agricultural and Forestry Experiment Station of the University of Alaska. Slowly, I have been assuming the responsibility of the workshop and group. This has been a year of transition and the forthcoming year will equally exciting.

At this time, I would like to sincerely thank the organizers and hosts of the Edmundston, New Brunswick workshop: Dr. David Winston of the Canadian Forestry Service, Ottawa, Ontario, and Mr. Peter Etheridge of J.D. Irving Limited, Sussex: New Brunswick and his colleagues from St. Leonard, New Brunswick for their considerable efforts. Also appreciated are the time and efforts of the authors of the papers in this publication.



EXPERIENCES AND RESEARCH ON YIELD IMPACTS OF  
ARTIFICIAL REGENERATION AT HIGH LATITUDES IN  
FINLAND

Mauri Timonen and Martti Varmola

**Abstract.**--Artificial regeneration has been used in Finnish Lapland from the 1910's. It is normally used on sites where natural regeneration will not succeed. The most promising results have been achieved when converting thick-moss spruce stands to pine stands. However, extreme conditions have caused partial or total failures especially on high altitudes.

RESEARCH AREA

Finland lies in Fennoscandia between latitudes  $60^{\circ}$  and  $70^{\circ}$  N. The southernmost coast belongs to the Central European hemiboreal zone, and the other parts to the boreal zone. The boreal zone changes to the subarctic zone in the northernmost part of Lapland. This paper is mainly concerned with the yield impacts of artificial regeneration in Finnish Lapland, i.e. the north-boreal zone between latitudes  $66^{\circ}$  and  $70^{\circ}$  N (fig. 1).

CLIMATE IN LAPLAND

The climate in Lapland is cool, but thanks to the proximity of the Gulf Stream and the warm winds coming from the south-west it is more favourable

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Figure 1.--The geographical location of Lapland, the research area.

able than in parts of Siberia, Alaska or Canada, for instance, lying on the same latitudes. The mean temperature for June is  $+14^{\circ}$  -  $+16^{\circ}$  C ( $+57^{\circ}$  -  $+61^{\circ}$  F) and for February  $-13^{\circ}$  -  $-10^{\circ}$  ( $9^{\circ}$  -  $14^{\circ}$  F). The length of the growing season, i.e. the period

during the year when the daily mean temperature is above +5° C (41° F), is 120 - 145 days. The mean effective temperature sum during the growing season, using the same threshold value, is 500-900 d.d. The timberline lies roughly along the 550 d.d. line and at a height of 400 m (1300 ft) above sea level. The annual precipitation is 400 - 500 mm (160 - 200 in) of which almost half is snow. The climate is very humid, owing to the fact that evaporation in the summertime is even smaller than the precipitation.

Fluctuations in the climate are strong. The annual growth of the forests may vary by 30 - 40 % from the long term mean index. The magnitude of the fluctuations are the greater, the further north the regions are situated.

### TREE SPECIES

Scots pine (*Pinus silvestris* L.) is the most important tree species in Lapland. It covers about 70 % of the forest land and also grows further to the north than Norway spruce (*Picea abies* Karst.). In addition to these two conifers there are a couple of broad-leaved trees which have some commercial importance. Pubescent birch (*Betula pubescens* Ehrh.) is common especially on peatlands, but it is used mostly as pulp wood. Silver birch (*Betula pendula* Roth.) grows on sites of the best forest type. European aspen (*Populus tremula* L.) grows even further to the north than Scots pine, but the timberline is covered by mountain birch (*Betula tortuosa* Led.) which, however, has no commercial importance.

### THE HISTORY OF ARTIFICIAL REGENERATION IN LAPLAND

Forests have been regenerated artificially in Lapland from the beginning of this century. Most of the activity was originally of an experimental nature. Already in the 1910's sowing experiments were made with pine above the timberline even, and owing to the favourable conditions they have grown remarkably well. However, artificial regeneration work was not started on a large scale until the beginning of the 1960's.

The most problematic question in Lapland has been the regeneration of old spruce stands. They often grow on rather moist sites of the *Hylocomium-myrtillus* type (HMT-type), (Cajander 1949). The old stands are without exception seriously decayed and their growth has ceased.

Already in the 1920's promising results were achieved in HMT-forests following clearcutting, prescribed burning and changing the tree species to pine. The decisive research effort concerning the problem of regeneration was undoubtedly made by Prof. G. Sirén. His doctoral dissertation, presented in 1955, dealt extensively with the development of thick-moss spruce stands. He came to the conclusion that spruce stands of the thick moss type represented, in the north, a degenerative secondary stage of the rather fertile *Myrtillus*-type, the potential fertility of this secondary phase being higher than it is at the present.

Converting thick-moss spruce stands, by means of clearcutting and reforestation into their fertile primary stage was from then on the principal aim of forestry programmes affecting Lapland (Leikola 1979). Thus the regeneration method involving clearcutting, soil preparation and sowing, and later on planting with pine became the most popular one. In the 1960's the new method was particularly unsuccessful on high elevations, where severe damage appeared in the plantations. The main reasons were the exceptionally cool summers, which led to epidemics of various fungal diseases and the use of seed of too southern an origin which could not withstand the extreme weather conditions in Lapland. In the 1960's, after the first serious outbreaks of damage, it was thought that a thorough site preparation method, plowing, would improve the soil conditions. This resulted in it becoming the most popular method of site preparation. During recent years, however, plowing has frequently been criticized as being a method which is too drastic. It has also been used on sites where a lighter method would probably have been sufficient.

As mentioned above, carrying out artificial regeneration on a large scale is a relatively young, less than 30 years old practice in Lapland.

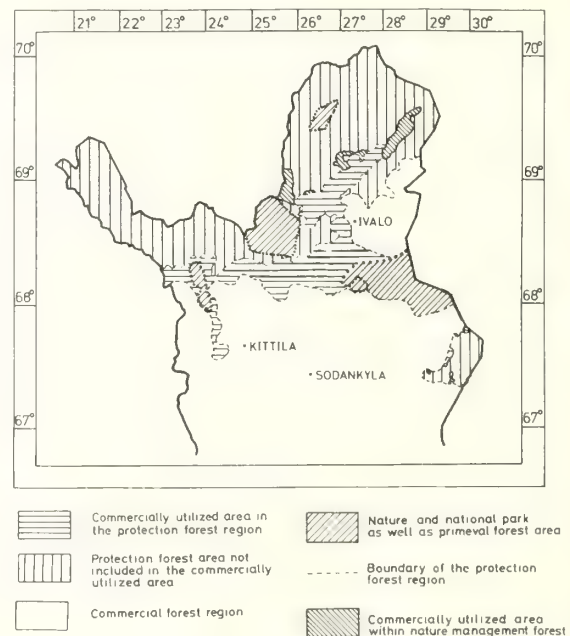


Figure 2.--Land-use classes and protection areas on forestry land in Lapland.

Thus we do not yet have enough results about the yield advantages. Most of the experiments have concentrated on developing different methods which can be used in artificial regeneration. Nowadays the most important question is how to produce viable conifer plantations with a good rate of growth. In conifer plantations established in 1965-1975 by private owners, for instance, only 1/3 of the trees were still capable of further growth in 1983. Thus it is a little difficult to talk about yield advantages, when the main ques-

THE RESULTS OF ARTIFICIAL REGENERATION ON THE  
POLAR TIMBERLINE

The reforestation result in the protection forest area was quite satisfactory, even better than that in the southern part of Lapland. The mean number of all types of seedling was 1771 trees per hectar (717/acre), of which 45 % were natural seedlings. About 1 000 seedlings per hectar (405/acre) (57 %) were classified, on the average, as being capable of further development. Regionally the number of seedlings varied from 730 to 1520 per hectar (297 - 620/acre) (fig. 3).

The oldest plantations growing on the timberline and north of it were over 60 years old. During this period fluctuations in the macroclimate and the density of plantations were observed. The warm period in the 1930's had brought about better results and the cold 1960's poorer, on the average.

Some other interesting results were found: The number of stems in plantations at altitudes of over 300 m (980 ft) above sea level was clearly lower than in plantations under 300 m. No differences were found between the number of trees in planted and in sown stands, but the transplants had a greater diameter in the planted stands. Plowing was found to improve the success of reforestation. The effect of slope was a positive factor. Stoniness, small mounds and depressions had a negative effect on the success of reforestation.

In the light of the stem number, the fact that the result of artificial regeneration above the timberline was surprisingly satisfactory, is an interesting phenomenon (fig. 3, Pakanajoki and Utsjoki area). The development of the cultivations was slow. Dominant height at the age of 60 years was only 6 meters (20 ft) and volume 6 m<sup>3</sup>/ha (86 cu.ft./acre).

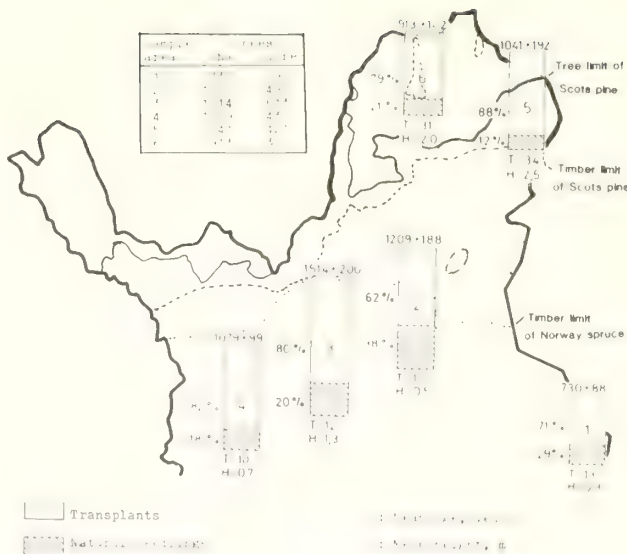


Figure 3.--Number of satisfactory young trees in sample areas: 1 = Tuntsa, 2 = Laanila-Vuotso, 3 = Sammelselkä, 4 = Kittilä, 5 = Pakanajoki and 6 = Utsjoki.

Vuokila and Väliaho (1980) have discussed the yield advantages between natural and cultivated forests. Their conclusions were based on the idea that all necessary thinnings are carried out in accordance with the yield and growth models for coniferous plantations in Finland. The yield estimates and conclusions may be too optimistic when applied to Lapland, because the material of the models is mainly based on the forests of southern Finland. The natural conditions in the north are very extreme, which means a loss in total yield. However, their growth and yield tables give the best information about the maximum yield advantages during the whole rotation period in Lapland.

## Yield differences between artificial and naturally regenerated stands

According to Vuokila and Väliaho, conifer plantations do not produce more in terms of volume than natural stands when grown on sites of the same type, provided that both are managed from the very beginning. In practice the advantage of artificial regeneration can be seen as a quantitative rise in wood production. On good sites especially, there are no real alternatives to artificial regeneration, because natural regeneration is not usually successful on such sites. An increase in wood production can also be expected if a natural stand originates with openings or it is so uneven that part of the site potential is initially left unexploited.

In conifer plantations there will be a "volume growth loss" in comparison to natural stands. This is due to the wide spacing at the seedling stage and to the strong decrease in the growing stock at an older age. While the stem number at



the end of the rotation period in natural stands is over 1 000 stems/ha (400/acre), the corresponding figure is only 400-500 stems/ha (160-200/acre) in commercial forests.

As regards the total volume yield, it would appear that natural regeneration should always be used, whenever possible, in reforestation work. This presupposes that the seedling stock is fully established within a reasonable period of time. In the case of spruce, planting is the only proper method. As regards pine, on the other hand, direct seeding is preferable to planting on sites poorer than the average. On better sites also pine should be planted. The advantage of direct seeding in comparison to planting is the better subsequent quality of the growing stock.

Depending on the site, natural normal, untreated pine stands produce 0,6 - 1,2 m<sup>3</sup>/ha/year incl. bark (8,6 - 17,2 cu.ft./acre/year) more timber than plantations (fig. 4). Although, proportionally, the loss in a plantation is greatest on poor sites, it is important also on all sites. If we take into account only the growing stock remaining at the end of rotation period, plantations with thinnings gives a greater yield of 0,5 - 1,2 m<sup>3</sup>/ha/year incl. bark (7,1 - 17,2 cu.ft./acre/year).

#### Yield advantages of artificial regeneration on certain sites

The advantages of artificial regeneration on certain sites have to be sought from the structure of the yield, rapid development of the trees and shortening of the rotation period. The wood production of cultivated forests can be guided in the desired direction by applying different thinning programs, developed by Vuokila and Väliäho (1980).

Artificial regeneration is an efficient means of producing sawlog trees and very large-dimensioned timber. According to Vuokila (1970), 900 log stems/ha (360/acre) can be achieved on sites with site index  $H_{100}=24$  ( $H_{100}$  = the dominant height at the age of 100 years) during the rotation period by applying repeated moderate thinnings. Using a selection type thinning it is possible to obtain a practical maximum of 1100 - 1200 log stems/ha (450 - 490/acre).

In artificial regeneration, an initial low stem number coupled with intensive silviculturally activating low thinnings accelerates the diameter growth in a way which cannot easily be achieved in natural regeneration. The production of logs of 750/ha (300/acre) is, however, lower than the normal level. This yield is 70 % of the maximum to be achieved in practice. As a result, however, the timber is larger-sized than average, particularly in the final felling.

Every year which is gained in growing a new plantation means an increase of one percent in the wood production during the next 100 years on the same site. In many cases, however, artificial regeneration shortens the rotation time by 5 - 15

years in comparison to natural regeneration under Finnish conditions (Putkisto 1980). In addition to this, intensive low thinnings shorten the rotation time by 15 - 20 years (Vuokila 1980).

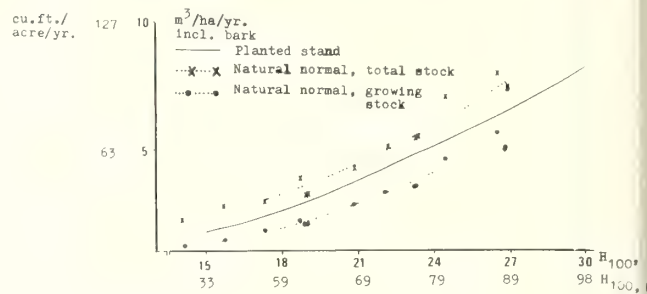


Figure 4.--The mean annual volume growth of cultivations during the rotation time as a function of site index (Vuokila and Väliäho 1980) compared to the corresponding growth values of the total and growing stock in natural normal forests (Ilvessalo 1975) according to Vuokila (1982).

#### Artificial regeneration of Hylocomium-myrtillus-site type forests

One very interesting question is the possible yield advantage that can be achieved by converting the old HMT-type spruce stands into pine stands by direct seeding or planting. According to Ilvessalo (1937), a spruce stand on a site of the HMT-type grows very slowly, and reaches a dominant height of 11 m (36 ft) in 100 years, 18 m (59 ft) in 200 years and 20 m (66 ft) in 260 years. Gustavsen (1980) classified HMT-type spruce forests in the site index class  $H_{100} = 12 - 15$  m. However, Vuokila and Väliäho (1980) have classified pine plantations on HMT-type sites in the site index class  $H_{100} = 21$  m. The difference between naturally regenerated spruce and artificially regenerated pine stands is remarkable. Ilvessalo (1937) quotes a yield of only 64 m<sup>3</sup>/ha (915 cu.ft./acre) for spruce whereas Vuokila and Väliäho (1980), depending on the type of thinning program used, report a yield of 410 - 490 m<sup>3</sup>/ha (5900 - 7000 cu.ft./acre) for pine in 120 years. In the figures presented by Vuokila and Väliäho the stands must be fully-stocked and they must not have suffered from any damage.

#### Problems of artificial regeneration in Lapland

Artificial regeneration is a very useful tool for forest management, since all the work can be scheduled precisely. Natural regeneration is much more difficult in this respect. In spite of the advantages of artificial regeneration there are also some drawbacks that restrict its use in practice in Lapland. Two important problems are discussed.

One of the main problems is the difficulty of regeneration at high altitudes. Climatic fluctuations, unsuitable seed origin and other factors may cause partial or total failures of reforestation. In some difficult areas the establishment

of a plantation may take years, sometimes decades. In such a case, the plantation may not be fully established until the next warm period occurs. The very best regeneration methods for these extreme conditions have presumably not yet been developed. The establishment of a new forest at high altitudes may well succeed with time, but it may involve considerably high costs.

Attention has been drawn to the deterioration of the technical quality of the wood sites throughout the whole of Finland. Wide spacing in plantations increases branchiness, which weakens the use of stems as high-quality lumber. In practice this problem can be avoided by the selection of proper tree species or by pruning, if a stand already exists.

As a rule, artificial regeneration methods work well enough to ensure the rotation of tree generations.

#### CONCLUSIONS CONCERNING THE ADVANTAGES OF ARTIFICIAL REGENERATION

The first role of artificial regeneration is the establishment of new forests. Natural regeneration is the main method in cases where the conditions are favourable. Artificial regeneration has to be used when natural regeneration gives unsatisfactory results. Its advantages are of course the greater, the more it helps to establish and complete new stands.

The second role of artificial regeneration can be found in individual forests. On certain sites it is not possible, in practice, to increase wood production by artificial regeneration. Its advantages can be found in the improvement of the structure of the yield, the development of trees and the shortening of the rotation period.

The most promising results with artificial regeneration in Finnish Lapland have been achieved when converting thick-moss spruce stands to pine stands. Changing the tree species from spruce to pine can increase the total yield manyfold. This, however, is more theory than practice, because the growth losses due to failures in regeneration, damage during the rotation period and fluctuations in the climate may be significant. The failures are most probable at high altitudes.

Increasing the dimensions of the growing stock and striving for high technical quality are conflicting production targets especially on good sites. In order to guarantee high-quality forests in the future pruning and other methods are being developed.

Artificial regeneration is a popular method in establishing a new forest. It is used on sites where natural regeneration will probably not succeed. It seems to work in Lapland, on the timberline and above it. However, it is recommended to be used only when the other methods available do not work enough well.

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# THE IMPACT OF ARTIFICIAL REGENERATION ON ROTATION AGE IN NORWAY SPRUCE AND SCOTS PINE AREAS IN NORWAY

Martin Sandvik

**ABSTRACT:** The possibilities for natural regeneration are considered related to site quality and altitude. The most fertile sites have to be artificially regenerated. On medium and poor sites natural regeneration may be achieved. The effect on rotation age reaches from -6 to +40 years compared to artificial regeneration. Lodgepole pine survived and grew better than Scots pine at high altitudes.

## INTRODUCTION

The effect of artificial regeneration on rotation age depends primarily on the conditions for natural regeneration created by the climatic and edaphic factors. Climatic factors are decisive in flowering induction and seed maturation as well as germination and seedling establishment. Site quality affects the germination and establishment processes mainly by vegetation competition and drainage conditions. This article is dealing with some observations and experimental results concerning the variability in conditions for natural regeneration of *Picea abies* and *Pinus sylvestris* in Norway. Figure 1 shows Norway situated from 58° to 71,5°N, with the native conifers growing primarily in the southeastern and the central parts of the country. The timber line is reaching 1,000 meters above sea level in the southern central Norway at its maximum, and decreases rapidly towards west coast and more slowly to the north. Nearly 1/3 of the total forest area of Norway is situated close to the timber line where low summer temperature restricts natural regeneration most heavily.

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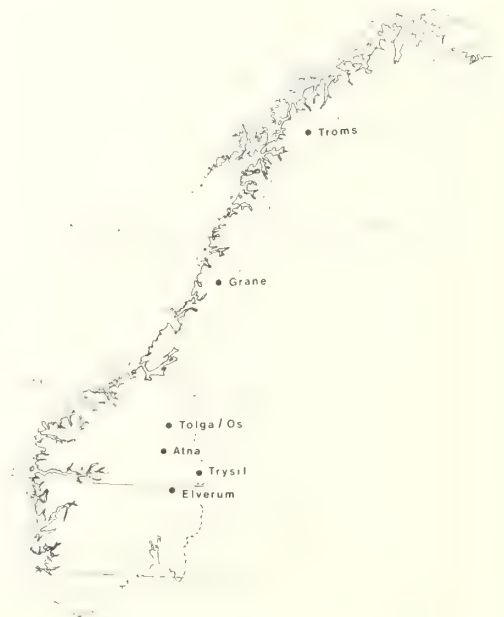


Figure 1.--Distribution of the experimental plots described in Norway.



## FLOWERING AND SEED MATURATION

In Norway spruce the induction of flower buds depends on a fairly high temperature producing a water deficit in the current year shoots within a rather short period in early summer. Cone and seed development the following year is most dependent

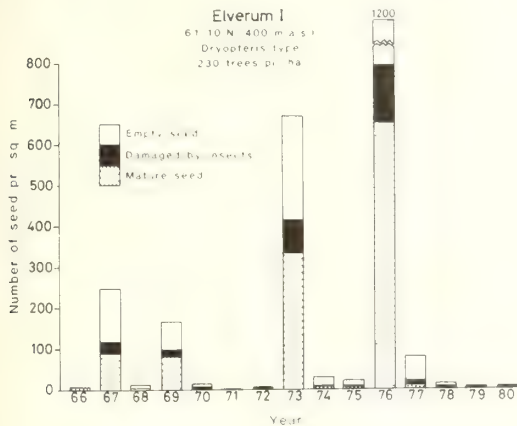


Figure 2.--Seed harvest in spruce shelterwood.

dent on the heat sum between the flushing in spring and the first frost in the autumn. The probability for these temperature requirements to be fulfilled in two subsequent years is obviously decreasing with both latitude and altitude. It is also an experience that the temperature requirement for flower induction is more frequently met than the heat sum requirement for seed maturation the following year in the marginal areas for spruce forests. Approaching the timber line 20 - 30 years may elapse between seed years of any significance in the regeneration process (York 1969). Also at lower altitudes seed production in spruce occurs periodically with increasing intervals towards the north. Figure 2 is reproduced from Skoklefeldt (1983) and illustrates the seed years at a locality in southern Norway from 1966 to 1980. In this part of the country seed years may occur with 3 to 8 years intervals. It is a common feature that pollination and seed quality are positively correlated with the flowering intensity.

In Scots pine seed years are more frequent than in Norway spruce as seen from figure 3 (Skoklefeldt 1983). This behaviour may depend partly on the fact that the pine forest usually occupies the most dry and poor soils where water deficits are easily introduced during warm days in early summer, and where restriction of vegetative growth by nutrient shortage is most pronounced.

## GERMINATION AND EARLY DEVELOPMENT

Germination conditions are strongly dependent on the site quality. On the best sites spruce germinants are easily outgrown by the vigorous ground vegetation. With a stem-wood production potential of 10 - 20 m<sup>3</sup>/ha a year, those sites are considered as obligate planting areas in Norway. Natural regeneration of spruce is most easily raised on medium sites belonging to the *Dryopteris* type, either as in advance regeneration towards the end of the

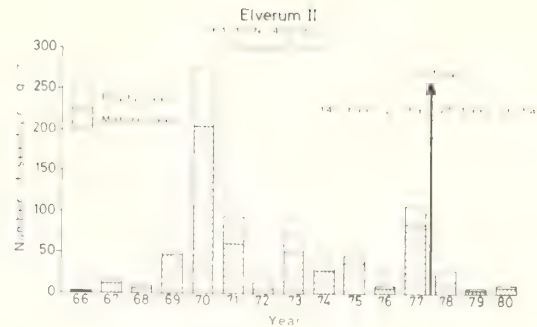


Figure 3.--Seed harvest in a seed tree cutting of pine.

stand phase or after a shelterwood cutting. Results from regeneration studies carried out by Skoklefeldt (1983) in the southeastern part of the country and by Bergan (1971) in North Norway are presented in figures 4 - 10.

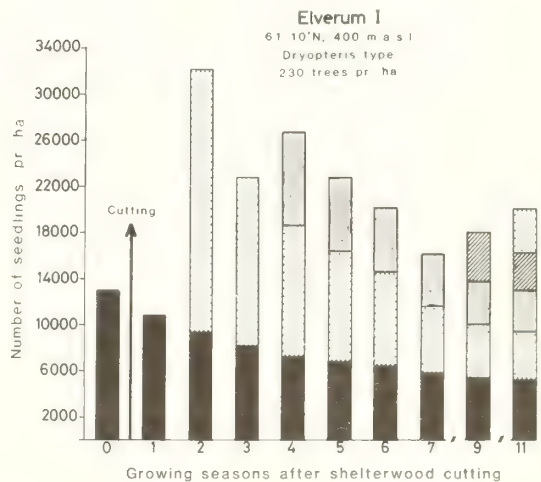


Figure 4.--Germination and mortality among seedlings from different seed years.

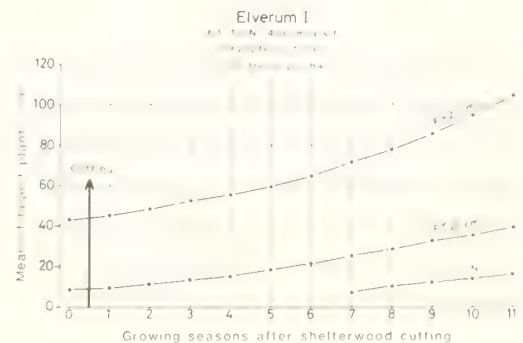


Figure 5.--Mean of highest plant in each 2 x 2 m square. F = advanced regeneration. N = regenerated after shelterwood cutting.

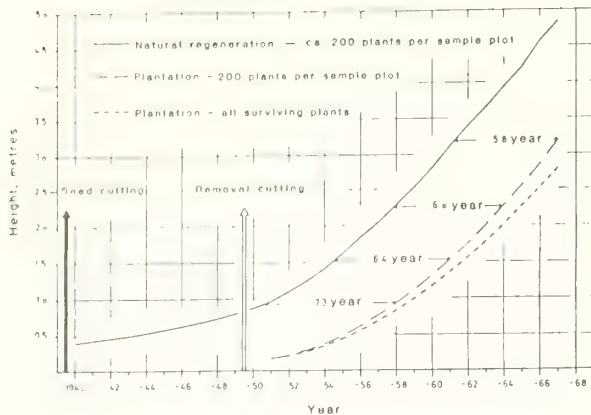


Figure 6.--Height growth of natural regeneration of spruce established before shelterwood cutting compared to seedlings planted just after shelterwood removal. Each sample plot = 900 sq.m.

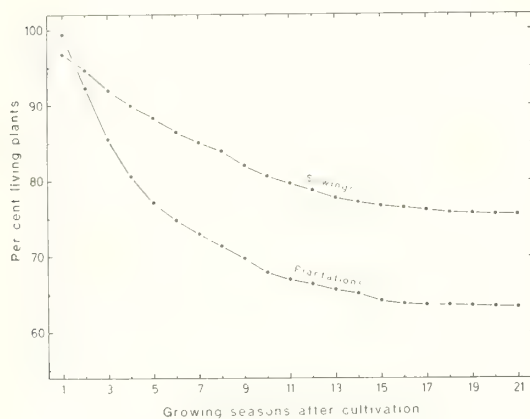


Figure 7.--Survival of planted 2 + 1 bareroot seedlings of Scots pine compared to per cent patches with living plants after direct seeding.

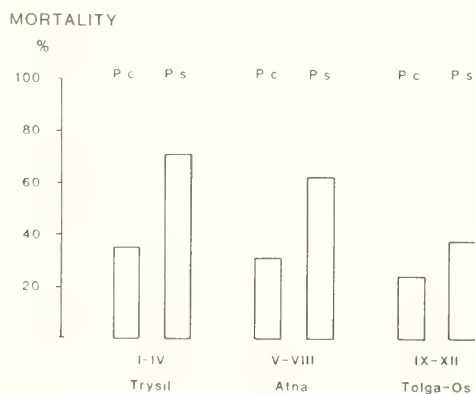


Figure 8.-- Mortality 7 years after comparative planting of lodgepole pine (P.C.) and Scots pine (P.S.) on 12 experimental plots in 3 different areas at high altitudes in southern Norway.

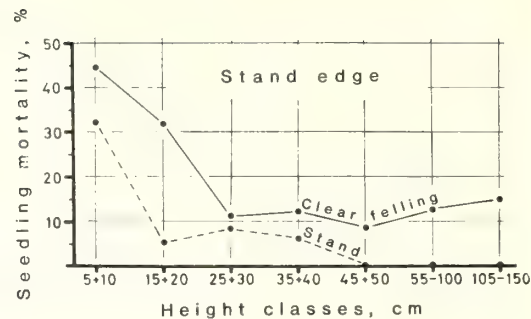


Figure 9.--Mortality among seedlings of different height classes after clear-cutting of stand edge. Regeneration on previously clearfelled area compared to regeneration within stand edge.

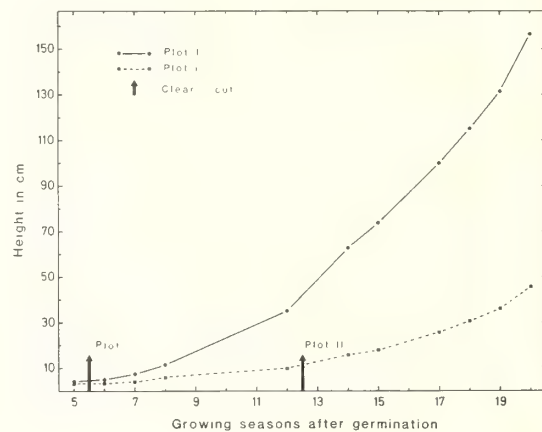


Figure 10.--Height growth of Scots pine seedlings after removal of the shelterwood at age 5 (Plot I) compared to removal at age 12 (Plot II) in Troms county.

By comparing figure 4 and figure 2, both from the same stand, it is seen that a rich seed harvest some years after the shelterwood cutting contributed less to the natural regeneration than a poor to medium seed harvest just after the cutting. Germination and seedling establishment were adversely effected by an increased competition from ground vegetation following the shelterwood cutting.

Attention should be paid to the contribution from the in advance regeneration and to the effect of different height classes on the rotation age.

At cutting age 11 (fig. 5) the development of in advance regeneration from the height class  $\geq 20$  cm was at least 15 years ahead of seedlings established during the shelterwood period.

Bergan (1971) in his study compared the development of in advance regeneration on a *Dryopteris* type with seedlings planted just after shelterwood removal (fig. 6). The in advance regeneration was 20 - 25 years old at the time of planting. At a plantation age of 16 the height development of the

in advance regeneration was approximately 6 years ahead of the planted seedlings. No additional regeneration occurred during the shelterwood period in this case. It is concluded from these experiments and others that in advance regeneration above 20 cm in height - even if the vitality of the plants looks poor - will secure the establishment of a new stand when the spacing is acceptable. On the other hand, where in advance regeneration is missing at the end of the stand phase, a seed year has to occur within 3 - 4 years after shelterwood cutting if a successful regeneration should be expected. Later on exposure of mineral soil by scarification would be a prerequisite for germination and seedling development. By scarification in a cone-year, natural regeneration may succeed also on the *Myrtillus* type where a thick humus layer otherwise obstructs germination and seedling establishment.

The less fertile *Vaccinium* type is most frequent on sediments and moraine areas in the lowland. In southeastern Norway mixed stands of spruce and pine are easily established, with spruce as in advance regeneration supplemented by pine during an edge regeneration or seed tree period.

In Troms, Bergen (1981) observed that natural regeneration mainly occurred in advance of seed tree cutting even in pure pine stands of the *Vaccinium* type. He also registered a higher frequency of empty scarified patches after planting of 2 + 1 bare rooted Scots pine seedlings than after direct seeding in a comparative study in the same area (fig. 7). At age 20, however, the height development of planted seedlings was 4 - 5 years ahead of direct seeding.

The poorest sites occur as *Cladonia* type in arid regions in the inland and as *Calluna* type in more humid climate in the coastal regions and at high altitudes in southeastern Norway. These types are typically pine areas. On the *Cladonia* type in advance regeneration is a common feature which may give rise to new stands at lower altitudes. At high and harsh areas - in the so-called mountain forest - both natural and artificial regeneration of Scots pine are frequently and heavily injured by fungi as *Phacidium infestans* and *Gremmeniella abietina*. This makes regeneration investments a hazardous one on those areas as far as Scots pine is concerned.

On the more wet *Calluna* type a thick rawhumus layer and the height and density of the ground vegetation offer very poor conditions for germination and seedling establishment. This type occurs also on shallow soil at low altitudes. Owing to the poor site quality the stand density is usually low, and Scots pine is often mixed with starving trees of Norway spruce. A clear cutting of spruce combined with a seed tree cutting of pine followed by scarification seems to be the most reasonable regeneration method on this type in the lowland. During the last decay, however, increasing attention is paid to afforest clear felled areas on poor sites with *Pinus contorta* also in Norway. This is particularly put in practice at high altitudes where regeneration of *Pinus silvestris* is experienced to be heavily injured by the above-mentioned fungi.

In figure 8 is presented average mortality 7 years after planting of *Pinus contorta* and *Pinus silvestris* on 12 experimental plots at high altitudes in southeastern Norway (Dietrichson & Tuttunen 1983).

In addition to the higher survival, lodgepole pine is expected to increase the yield by 20 - 30% and decrease the rotation age even more compared to established Scots pine.

#### REMOVAL OF SHELTER AND SEED TREES

During shelterwood or seed tree removal, logging operation and slash cover will cause a loss of seedlings. Factors affecting this loss may be shelterwood density and amount of slash, seedling height and the logging season. An example from a study on spruce shelterwood carried out in southeastern Norway by Skoklefeldt (1967) is shown in table 1.

Table 1--Seedling mortality in per cent on slash-covered and slashless ground after shelterwood removal Spruce

Height class (cm)	Slash cover	Height class (cm)						Total mortality
		5+10	15+20	25+30	35+40	45+50	55+100	
Summer	0	36.4	16.7	0	0	0	3.7	8.2
	10-25	31.3	11.1	24.0	0	12.5	0	22.5
	30-50	81.3	52.8	64.7	40.0	50.0	36.8	50.0
Winter	0	0	17.5	12.5	0	0	5.8	10.3
	10-25	0	22.2	40.0	11.1	40.0	37.5	31.3
	30-50	0	80.0	80.0	50.0	66.7	19.4	48.4
Spring	0	8.3	32.3	11.1	5.9	4.6	8.2	12.7
	10-25	50.0	17.7	0	0	0	0	9.1
	30-50	0	0	0	0	0	0	0

Seedling smaller than 25 - 30 cm are easily wasted during and after shelterwood removal. Mortality increases considerably with increasing amount of slash which also leads to a more irregular spacing. Felling season usually has less influence than suggested in table 1. The same detrimental effects of logging operations are also experienced when edge regeneration is applied instead of shelterwood cutting (fig. 9).

Bergen (1981) studied the effect of pine shelterwood on seedling growth in Troms.

At age 20 the height development was depressed by 6 years in rotation age when the shelterwood period was prolonged from 5 to 12 years (fig. 10). The difference in shelterwood yield, which was not observed in this case, has also to be considered when the best time for shelterwood removal is calculated from an economical point of view.

#### CONCLUDING REMARKS

Natural regeneration of Norway spruce and Scots pine is most profitable when occurring in advance towards the end of the stand phase. The seedlings height is critical for the survival after clear cutting and should be at least 20 - 40 cm, depending on the stand density and the amount and dispersal of slash. The vitality of in advance



spruce regeneration may be increased by a shelterwood period of 5 - 6 years. Experimental results from the northern part of Norway indicate a shortening of the rotation age by 5 - 6 years for this regeneration compared to regeneration by planting 2 + 2 bare rooted spruce seedlings.

On medium and poor sites with limited competition from the ground vegetation - i.e. on the *Dryopteris* and *Cladonia* types - a successful natural regeneration may be achieved by a shelterwood or seed tree cutting. Rotation age is then expected to be prolonged by 5 - 10 years in the lowland and until 40 years at high altitudes compared to plantations of vigorous seedlings. A successful breeding strategy may add years to these differences. On poor sites at high altitudes in Norway, afforestation by lodgepole pine seems profitable when established at a density of approximately 1,000 tress/ha.

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DEVELOPMENT OF WHITE SPRUCE PLANTATIONS  
AT THE PETAWAWA NATIONAL FORESTRY INSTITUTE  
CHALK RIVER, ONTARIO

W.M. Stiell

ABSTRACT: Growth and yield characteristics are reported for white spruce plantations established 1922 to 1940, mostly on old field sites. Main research was in thinning and the development of yield tables for unmanaged stands, based on site index and initial planted spacing. A widespread root rot, Polyporus tomentosus has caused significant mortality in some plantations.

## INTRODUCTION

### Location and Description

The Petawawa National Forestry Institute is located in the Ottawa River Valley, within the Middle Ottawa Section L.4c of the Great Lakes-St. Lawrence Forest Region (Rowe 1972), at 46°00'N latitude and 77°26'W longitude. The climate is continental and subhumid with consequent extremes of heat and cold. Some relevant statistics are as follows:

Mean annual temperature	4.3°C (39.7°F)
Extreme maximum temperature	38.9°C (102.0°F)
Extreme minimum temperature	-40.6°C (-41.1°F)

Minimum frost-free period	ca 100 days
Average growing season	136 days

Average total precipitation	82.2 cm (32.4 in)
-falling as rain	61.2 cm (24.1 in)
Average snowfall	210.4 cm (82.8 in)

The institute area may be considered lowland, ca 90 to 275 m (295 to 902 ft), and is generally undulating to flat. The entire area is underlain by Laurentian gneiss and granite. Six major landforms can be distinguished: (i) ridges and hills of shallow till; (ii) low ridges and hills of water-worked, more sandy till; (iii) broad rolls of moulded, loamy till; (iv) terrace outwash and delta sand plains; (v) sand dunes; and (vi) lakebed sands and silts. The dry climate and sandy landforms favour the natural occurrence of pine species.

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The first forest exploitation was in the extensive stands of white and red pine<sup>1/</sup> then prevalent. Following logging and fire the second growth forest (post 1878) was predominantly mixed in character and represented numerous species. Conifers included white, red, and jack pine, black and white spruce, tamarack, balsam fir and white cedar; and hardwoods trembling and large-tooth aspen, white and yellow birch, red and sugar maple, beech and basswood.

Some of the Institute lands were cleared for settlement, with further associated fires, but generally they proved submarginal for agriculture. In 1904 the area was purchased from the Ontario Government by the military authorities, and privately owned lands within it were all expropriated by 1910. In 1917 the Canadian Forestry Service, at the request of Dept. National Defence, took over management of the forest on the military lands--about 260 km<sup>2</sup> (100 mi<sup>2</sup>), and a few years later embarked on a program of forest research; this program still continues on a more limited area of 98 km<sup>2</sup> (38 mi<sup>2</sup>).

One of the early forestry efforts was to plant up the abandoned fields which had been standing fallow since 1910; later poorly stocked old burns were reforested as well.

#### Planting Sites

The commonest plantation soils are waterlaid sands and gravels (some interbanded with or overlain by lacustrine silts or windblown sands), and moulded tills which overlay bedrock--usually for a depth of a few metres. These soils are somewhat acid about pH 6 in the upper 7.5 to 10 cm (3 to 4 in). They are weakly podsolized, and have poorly developed profiles with L, F, A<sub>2</sub>, and B horizons, usually farmed to an As B type. Fertility is low, but foliar analysis indicates that windblown materials contain more available nutrients. Parent materials are chiefly siliceous, with small amounts of feldspar and biotites. At the time of planting, the old fields were free of tree growth, with the exception of occasional volunteers. They supported a herbaceous cover which had formed a moderately heavy sod or, on the drier sites, a blueberry--sweet fern (Vaccinium-Comptonia) type of vegetation.

About 9% of these plantations were in pure stands of white spruce, with 34 stands being planted from 1922 to 1940. The object of these test plantations was to find out how the species would perform on the soils in question, and at various spacings, and growth and yield studies made in them is the subject of this paper.

<sup>1/</sup> Scientific names of tree species are those in R.C. Hosie's Native Trees of Canada, 8th ed. (Fitzhenry & Whiteside, Don Mills, Ont., 1979).

A separate program, which will merely be touched on here is tree genetics and breeding. Small trials comparing the growth of white spruce from Petawawa, Quebec and the Maritimes were planted in 1922 and 1936, but it was after 1949 that there was a major expansion in research on the genetics of this species. This work included the study of variation among provenances grown from seed collected in stands throughout the range of white spruce, the study of variation among individual trees in a single stand, and the testing of progeny from the controlled breeding of selected trees. The provenance research, which involved large-scale trials not only at Petawawa but elsewhere in Canada and the United States of America, has identified some provenances giving superior performance over a wide range of locations where they were planted. Notably, this apparent superiority, so far to age 30 years or less, is exhibited by provenances from locations in the Upper Ottawa Valley, such as Beachburg and Douglas. Results of other research have shown that there is also a large amount of genetic variation in growth rate among individual trees. Present research places greater emphasis on the development and testing of effective ways to harness the variation in this species for the production of genetically improved planting stock<sup>2/</sup> for use in forest renewal now and in the future.

#### GROWTH AND YIELD OF TEST PLANTATIONS

##### Sample Plots

First observations in the plantations were taken at a young age, involving systematic samples of survival and total height in a certain proportion of rows. The main vehicle for research however are permanent sample plots (PSPs) of which ca 60 were ultimately established in white spruce. On each of these every tree is permanently identified with a numbered tag at breast height, its position mapped and its measurements recorded separately.

PSP measurements are usually carried out at 10-year intervals, although a 5-year remeasurement may be made for short-term growth determination. Characteristically at measurement, d.b.h. is taken on all trees with a diameter tape, and a smaller, systematic sample is taken of tree height and form class. Special purpose measurements, e.g. crown length and width, diameters at other points on the stem, or cone counts may be taken on a subsample. Observations are now accumulated in the field with a Datatype recorder. Compilation is carried out by computer, and includes the solution of parabolic equations for height/diameter relationships and

<sup>2/</sup> Information provided by Dr. Gordon Murray, Tree Breeding and Tree Genetics Project, Petawawa National Forestry Institute.



the calculation of tree volumes from volume tables. The data are printed out in stand tables which give numbers of trees, basal area, total volume and merchantable volume for each 2-cm diameter class, as well as sub-totals and per-plot and per-hectare totals. Biomass of individual tree components and of the whole tree may also be calculated.

### Growth Characteristics

Height growth of plantation white spruce at Petawawa does not appear to be consistently related to physiographic site, as defined by soil parent material or moisture regime (Hills and Pierpoint 1960), with plantations over the range of moisture regimes encountered (1 to 5) being found in every site index class (Stiell and Berry 1973). Considerable variation in early height growth is found, with time to reach breast height ranging from 6 to 12 years. That within-stand variability is sustained was shown in one sample of plantations, from 1.5 m (5 ft) to 9 m (30 ft) tall, where the coefficient of variation in average height was almost constant at ca 31% (Stiell 1955). Height growth, therefore, cannot be predicted with much assurance before a stand age of 15 to 20 years. Owing to shade tolerance of the species, large numbers of smaller trees survive long after the crowns have closed over them, ultimately succumbing to suppression.

The range of diameters in a stand is likewise quite wide and increases with mean diameter at breast height. About a 25.4-cm (10-in) spread is not unusual in plantations with mean dbh of 12.7, 15.2 or 17.8 cm (5, 6 or 7 in). The mean is strongly influenced by stocking level, increasing with wider spacings.

Closed canopies are extremely dense, shading out nearly all ground vegetation. In these conditions the ratio of the live crown length to total height can exceed 50% for dominant trees, and dead branches below the crown can persist in a sound condition for at least 25 years. Oven-dry foliage weights of up to 25 kg (55 lb) were found for individual crowns, and 14,515 kg/ha (12,950 lb/ac) (Stiell 1969).

Root excavations in thinned and unthinned parts of a 39-year-old plantation growing on deep sands showed mean radial spread of laterals up to 78% of the height of a dominant tree 17.1 m (56 ft) tall. The laterals, mostly occurring in the top 0.3 m (1 ft) of soil, were still increasing at ca 0.3 m/yr. Taproots and sinkers were common, descending as deeply as 3 m (10 ft). Intertree grafting was common in both parts of the stand (Grose 1968).

### Insects and Diseases

Four main pests have concerned these plantations. An outbreak of spruce budworm (Choristoneura fumiferana Clem.) in the late 1960's and early 1970's was successfully controlled on research areas by annually spraying them with chemicals from the air. A root rot Armillaria mellea (Vahl ex Fr.) Kummer has killed potential crop trees at

scattered points throughout the plantations. A stem canker Cytospora kunzei Sacc. is prevalent and recurs in managed plantations even after thinning infected trees. This canker, observed to be self-limiting in a number of instances, is not considered to pose much of a threat at Petawawa.

Much more serious is the root rot caused by Polyporus tomentosus Fr. This disease, widespread in the boreal forest, and identified in planted white spruce from Saskatchewan to Nova Scotia and Prince Edward Island is spread by root-to-root contact (Whitney 1977). Death of trees in groups often occurs. There does not seem to be natural immunity and all sizes of trees can be affected although the smaller ones succumb more quickly. The fungus grows slowly, taking at least 15 to 20 years to kill a tree after infection. At Petawawa the disease usually does not appear in plantations less than 25 or 30 years old. There is no feasible control measure yet.

### Volume Tables

Since pure stands of white spruce rarely occur in the natural forests of central Canada a study of tree taper and volume was undertaken for the plantations, involving the felling and sectioning of 455 trees. Tables of total cubic volume, merchantable cubic volume, and board foot volumes, as well as taper curves by 1-in dbh and 10-ft height classes, were prepared (Berry 1969). A cubic-metre version of the total volume table for trees 4 to 22 m tall and 4 to 40 cm in diameter was subsequently derived (Berry 1980). These tables are directly applicable to plantation trees.

### Yield Tables

Accumulated plot data have been used to develop yield tables for untreated plantations by 5-year age classes, based on site index and initial planted spacing. Utilizing data only from those plots showing high initial survival and in which virtually all subsequent mortality has been due to mutual competition, these tables have passed through several editions, having been updated and extended after successive remeasurements (Stiell and Berry 1967 and 1973, Berry 1978).

The general method of construction was to estimate stand parameters at successive ages according to regressions relating them to various combinations of dominant height and spacing (trees/ha) (Stiell 1973). The first step was to prepare a set of anamorphic site index curves showing dominant height in metres for SI Classes 15, 18, 21, and 24 m (49.2, 59.0, 68.9, and 78.7 ft) at base age 50 years from planting. Next, a set of survival curves, based on initial spacing and dominant height, was generated by predicting numbers of trees dying from suppression for each 1-m increase in stand height. At each 5-year interval, basal area and total volume were calculated from regressions relating them to the numbers of trees and dominant height of the stand at that age. Mean diameter was calculated

Table 1--Yield table for unmanaged white spruce plantations (site index 21)

Age from plant- ing (years)	Domin- ant height (m)	Average height (m)	Planted spacing (m)	Trees per ha (no.)	Mean d.b.h. (cm)	Basal area/ha (m <sup>2</sup> )	Volume/ha		Mass/ha		
							Total	Merch	Total tree	Total stem & bark	Merch stem & bark
							(m <sup>3</sup> )	(m <sup>3</sup> )	(t)	(t)	(t)
20	8.4	6.4	(1.25	5820	7.40	25.1	88	43	44	37	18)
			1.50	4160	8.28	22.4	78	44	39	33	19
			1.75	3148	9.08	20.4	70	44	35	30	19
			2.00	2467	9.83	18.7	64	43	32	27	18
			(2.50	1600	11.28	16.0	54	42	27	23	18)
			(3.00	1111	12.62	13.9	47	39	24	20	16)
25	11.0	8.5	(1.25	5175	9.14	34.0	152	102	76	65	44)
			1.50	3774	10.19	30.8	135	96	68	57	40
			1.75	2920	11.13	28.4	124	95	62	53	41
			2.00	2340	11.99	26.4	114	91	57	49	39
			(2.50	1591	13.65	23.3	99	86	50	42	37)
			(3.00	1111	15.38	20.6	87	79	44	37	34)
30	13.6	10.7	(1.25	4477	10.94	42.1	226	176	113	96	75)
			1.50	3312	12.15	38.4	203	162	102	86	69
			1.75	2613	13.19	35.7	186	154	93	79	66
			2.00	2137	14.16	33.6	174	148	87	74	63
			(2.50	1526	15.89	30.3	155	138	78	66	59)
			(3.00	1111	17.71	27.4	138	127	69	59	54)
35	15.9	12.8	(1.25	3790	12.72	48.2	295	245	148	126	105)
			1.50	2867	14.02	44.3	267	224	134	114	96
			1.75	2298	15.16	41.5	247	212	124	105	90
			2.00	1918	16.16	39.4	233	205	117	99	87
			(2.50	1426	17.91	35.9	210	191	105	89	81
			(3.00	1093	19.66	33.2	191	176	96	81	75)
40	17.9	14.8	(1.25	3230	14.40	52.6	355	302	178	151	128)
			1.50	2480	15.82	48.7	324	279	162	138	119
			1.75	2022	17.02	46.0	303	267	152	129	114
			2.00	1715	18.04	43.8	286	252	143	122	107
			(2.50	1320	19.78	40.5	261	238	131	111	101)
			(3.00	1053	21.40	37.9	242	223	121	103	95)
45	19.5	16.4	(1.25	2782	15.95	55.6	402	342	202	171	145)
			1.50	2180	17.41	51.9	371	323	186	158	137
			1.75	1804	18.63	49.2	348	306	174	148	130
			2.00	1551	19.64	47.0	330	294	165	141	125
			(2.50	1227	21.35	43.9	304	277	152	129	117)
			(3.00	1009	22.85	41.4	284	261	142	121	111)
50	21.0	18.0	(1.25	2414	17.50	58.1	446	379	224	190	161)
			1.50	1917	19.02	54.5	413	359	207	176	153
			1.75	1606	20.24	51.7	388	341	195	165	145
			2.00	1403	21.25	49.8	371	330	186	158	141
			(2.50	1139	22.89	46.9	346	315	173	147	134)
			(3.00	960	24.30	44.5	325	299	163	138	127)
55	22.1	19.2	(1.25	2148	18.79	59.6	476	405	239	203	173)
			1.50	1817	19.95	56.8	449	391	225	191	166
			1.75	1536	21.19	54.2	425	374	213	181	159
			2.00	1302	22.48	51.7	401	357	201	171	155
			(2.50	1075	24.06	48.9	376	342	189	160	146)
			(3.00	921	25.41	46.7	356	328	179	152	140)
60	23.2	20.5	(1.25	1928	20.07	61.0	506	430	254	215	183)
			1.50	1572	21.61	57.7	473	412	237	201	175
			1.75	1349	22.83	55.2	449	395	225	191	168
			2.00	1202	23.79	53.4	432	384	217	184	171
			(2.50	1010	25.29	50.7	406	369	204	173	157)
			(3.00	880	26.57	48.8	388	357	195	165	152)

Table 2--Total production, merchantable m<sup>3</sup>/ha (ft<sup>3</sup>/ac), after three thinnings from below

Residual basal area, m <sup>2</sup> /ha (ft <sup>2</sup> /ac)	18.4 (80)	25.3 (110)	32.1 (140)	Control
Thinnings 1958 + 1968 + 1978	148.9 (2128.0)	140.3 (2005.0)	109.0 (1557.8)	0.0 (0.0)
Mortality 1958-78	2.4 (34.3)	5.4 (77.2)	4.2 (60.0)	24.5 (350.1)
Volume 1978, after thinning	140.8 (2012.2)	194.8 (2783.9)	241.2 (3447.0)	310.4 (4436.0)
Total production	292.1 (4174.5)	340.5 (4866.1)	354.4 (5064.8)	334.9 (4786.1)

according to the corresponding numbers of trees and basal area/ha. Merchantable volume was derived as a percentage of total volume. Oven-dry biomass of the whole stand (kg/ha) was determined by multiplying total volume by basic wood density and by a factor to take into account bark, branches and foliage; and mass of the stem plus bark was taken as the product of total volume and wood density, increased by 10.3% to allow for bark (Alemdag 1983). The various regressions, or their constants, have been modified after each remeasurement as the additional data indicated.

The latest tables (unpublished) project values to age 60 years from planting, and are the first to include biomass values. Table 1 shows an example for a better than average site index class. In these tables, wider planted spacing (fewer numbers of trees) consistently shows greater mean dbh and smaller total volume/ha, and after ingrowth is complete, smaller merchantable volume as well. These differences become less important with age. For example plantations established at 2.0 x 2.0 m (ca 7 x 7 ft) appear to give a good compromise between dbh and branch thickness. At age 60, for SI 21, merchantable volume/ha at this spacing would be 93% of that at 1.50 x 1.50 m (5 x 5 ft), yet require planting of only 56% as many trees.

#### Thinning Trials

A number of thinning experiments were established, the first in 1958. These all involved thinning back to fixed basal areas (with control plots) at 10-year intervals, but used different marking methods (Berry 1974, Stiell 1980).

General trends were the same, with natural mortality heavily reduced in thinned stands. Despite wide growth variation between individuals in a dbh class, larger trees in each residual basal area consistently grew more in diameter than smaller ones; average growth for a given dbh class was greatest at lowest residual basal area; and growth in all circumstances was lower after the second treatment.

Of the residual basal areas tested, volume growth was similar at 25.3 m<sup>2</sup>/ha (110 ft<sup>2</sup>/ac) and 32.1 m<sup>2</sup>/ha (140 ft<sup>2</sup>/ac), but was reduced at 18.4 m<sup>2</sup>/ha (80 ft<sup>2</sup>/ac) and also on the controls. Pruned crop trees released by removal of compet-

ing dominants or codominants developed epicormic branches which would have to be removed if production of clear lumber was the objective. Table 2 shows results of thinning from below, after three treatments.

#### Future Development

The Polyporus root rot has led to significant mortality in a number of stands. As a result, those sample plots affected have had to be rejected for growth calculations. Lacking a direct control method for the disease, prognosis for the remaining stands is open to question.

Owners of badly infected plantations may find it advisable to clear cut them at a relatively early age—perhaps 40 to 50 years when the MAI of merchantable volume culminates in any case. Likewise, thinning under these circumstances is not likely to have much appeal if the potential of larger trees so produced will not be realized.

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## GROWTH AND DEVELOPMENT OF LARCH IN NEWFOUNDLAND

J. Peter Hall

**ABSTRACT:** Larch occurs widely throughout Newfoundland's boreal forests on a wide variety of sites and becomes established naturally after most types of disturbance. It grows faster and produces wood of higher density than other native conifers on most sites. Exotic species of larch have shown in plantation trials to grow even faster than native larch and to have considerable potential as reforestation species.

### THE FORESTS OF NEWFOUNDLAND

The island of Newfoundland covers 111 000 km<sup>2</sup> of which 100 000 km<sup>2</sup> is land area; of this 38 000 km<sup>2</sup> is productive forest land (Milne and Munro 1981). Productive forest land is defined as that producing at least 35 m<sup>3</sup>/ha at rotation. About three-quarters of the forest land is owned by the Crown, the remainder is owned by the two pulp and paper companies on the Island; Abitibi-Price and Bowater Newfoundland Limited. Over 80 percent of the growing stock comprises conifers and 87 percent of the wood harvested is for pulpwood.

The climate of the Island is typically boreal with cold winters, cool summers, late springs with the possibility of frost every month of the year. Rainfall is adequate for the growing season and there is normally a moisture surplus throughout the year (Damman 1983). The climate is moderated to a large degree by Maritime influences.

Most soils are derived from glacial tills and the underlying strata are mostly Palaeozoic sediments with varying amounts of intrusives. In eastern Newfoundland the underlying rock is mostly late-Precambrian sediments and volcanics. Profiles in most forest soils are podzols or humic-podzols. In western and central Newfoundland bogs and fens are common. In eastern Newfoundland soils tend to be thinner with bogs and wetland areas more common than in central Newfoundland.

Most of the productive forest land and nearly all areas under intensive forest management are located in three of the boreal forest regions described by Rowe (1972); Corner Brook (B28b), Grand Falls (B28a) and Avalon (B30) (fig. 1). The dominant species in the Corner Brook and Avalon sections is balsam fir (*Abies balsamea* (L.) Mill.) and in the Grand Falls section both balsam fir and black spruce (*Picea mariana* (Mill.) B.S.P.) predominate. Other species commonly found throughout the forests are white birch (*Betula papyrifera* Marsh.), trembling aspen (*Populus tremuloides* Michx.), white spruce (*Picea glauca* (Moench) Voss) and larch (*Larix laricina* (Du Roi) K. Koch). Larch, however, consists of about two percent of the total merchantable growing stock (cf. Khalil 1972). Several other species occur

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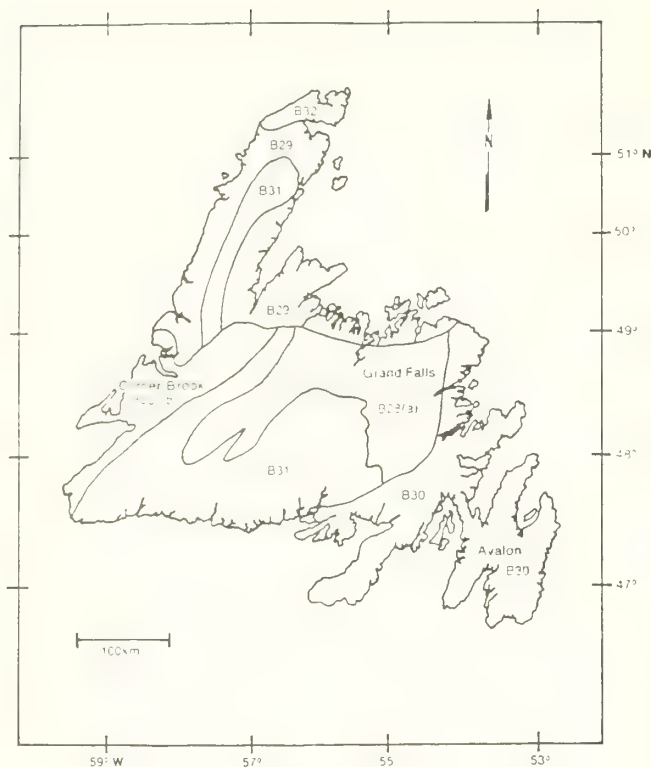


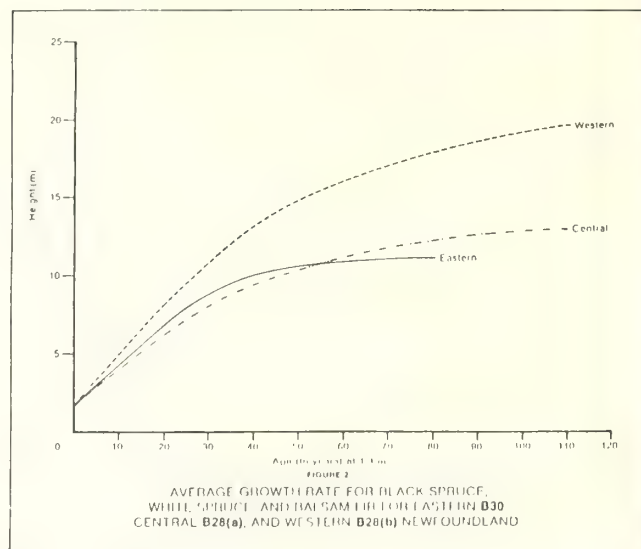
FIGURE 1

NEWFOUNDLAND SHOWING FOREST SECTIONS (ROWE 1972)  
AND NATURAL DISTRIBUTION OF LARCH

sporadically but are of no economic value because of their scarcity. Growth of the dominant black spruce and balsam fir is variable with the best growth occurring in the Corner Brook section and the slowest in the Avalon section (fig. 2). Climatic differences among the three sections are small; rainfall and temperatures are similar (except for total rainfall) (table 1). The most

Table 1--Climatic data for the three major forest sections in Newfoundland

Climatic factor	Forest Section		
	Avalon B30	Grand Falls B28a	Corner Brook B28b
Mean annual rainfall (mm)	1 445	937	940
Mean rainfall May to September (mm)	457	406	432
Average annual wind velocity (kph)	23.8	20.8	15.2
Mean temperature May to September, °C	12.8	12.8	12.8
Mean daily maximum temperature July, °C	21.1	22.2	22.2
Mean number of frost free days	116	103	96
Degree days above 5°C	2 000	2 000	2 000



significant difference is that of the average windspeed in the Avalon section which results in increased exposure and also adversely affects growth.

#### GROWTH OF LARCH IN NATURAL STANDS

Although larch occurs naturally throughout the productive forest areas it tends to be concentrated in central and eastern Newfoundland (fig.1). Pure stands of larch occur occasionally but it is most frequently found as scattered individuals in black spruce or black spruce-balsam fir stands. It grows under almost any forest conditions and one noticeable occurrence is on sites which have been mechanically disturbed for road construction or rights-of-way. All stands of larch in Newfoundland post-date the larch sawfly (*Pristiphora erichsonii* Hart.) epidemic of the 1880's which destroyed nearly all the larch stands in eastern North America (Webb and Drooz 1967).

An increased interest in larch in Newfoundland during the past decade has resulted in the initiation of studies on its distribution, growth and yield, possibilities of its use as a reforestation species and the potential for genetic improvement. Several exotic larch species are also being tested on various forest sites.

Part of the increased interest in larch is a result of the shrinking supplies of wood and the realization that greater utilization of forests includes harvesting species which had been considered non-merchantable for pulpwood. It is also becoming apparent that larch can be pulped with no reduction in product quality at least in quantities likely to be harvested with spruce and fir (Hunt 1979, Balatinecz 1982).

During the past decade a program of artificial reforestation has been underway in Newfoundland with the overall aim of increasing the black spruce component of pulpwood forests. Black spruce is the most desirable species currently in use because of its excellent pulping qualities and



its relative resistance to insects and diseases. (It is, however, declining in relative abundance. This decline is a consequence of improved fire protection programs and of clearcutting practices. The major source of natural black spruce stands is regeneration following wildfire; after clear-cutting balsam fir dominates the natural regeneration.) The reforestation program envisions the planting of six million seedlings in 1984, ten million in 1985 and for planting to remain at this level or increase in the future. There is therefore an opportunity to introduce other species into the program to increase forest productivity. Larch as a native species, biologically well adapted to Newfoundland, is an excellent species for testing in this way.

Larch has long been recognized as a fast-growing species; faster than its associates on most sites and for this reason it would seem to have high potential as a reforestation species (Fowells 1965, MacGillivray 1969). Much the same relationship was found when growth and yield data were collected for productive sites in Newfoundland where comparisons were made with black spruce and balsam fir (fig. 3). At the age of 50 years the superiority of larch over spruce and fir is about 2.5 m in height growth (Roberts and van Nostrand 1984). This translates into a significant eco-

nomie increase when applied to a reforestation program.

An analysis of three mixed black spruce larch stands in central Newfoundland showed similar trends (table 2). In all stands the larch has grown at a faster rate than the spruce and so have produced more biomass annually per tree (kg of dry matter per year). The increase ranged from 8-43 percent for stands at approximately rotation age (40-60 years). The data suggest an increased potential yield from using larch in reforestation programs.

A factor as important as rapid rate of growth of wood is that of specific gravity. The specific gravity of larch is normally greater than that of either black spruce or balsam fir (.49 compared to .36 or .34) (Panshin et al. 1964). Studies of wood specific gravity in Newfoundland black spruce stands were begun in 1980 and recently have been extended to larch and other species. The specific gravity of black spruce and larch in natural stands averaged .41 and .47 respectively. The range of specific gravity among trees within the stand, as expressed by the coefficient of variation, is about twice as great in larch stands as in black spruce stands <sup>1/</sup>. This greater variability within the stands provides an excellent opportunity for selection of superior individuals in a tree improvement program.

The data from natural stands show that larch grows faster than black spruce, produces more dry matter per unit of time than black spruce and hence shows considerable potential as a reforestation species.

#### GROWTH OF PLANTED NATIVE AND EXOTIC LARCHES

Exotic species are normally incorporated into reforestation programs because of some failing with the native species; either the native species cannot supply the needs of the forest industry or they have severe insect or disease problems. In Newfoundland the native species meet the demands of the forest industries for fibre but exotics

<sup>1/</sup> Hall, unpublished data.

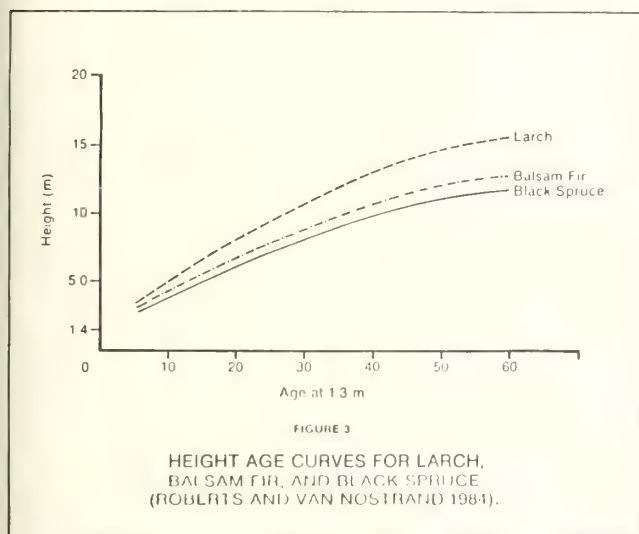


Table 2--Comparison of the growth of black spruce and larch in three mixed stands in central Newfoundland.

Stand	Age at 1.3 m	Diameter at 1.3 m	Average total height	Biomass <sup>1/</sup> kg/yr./tree	% increase over black spruce
Glenwood - Larch	45.7	22.0	14.7	3.06	8.1
Black spruce	52.9	20.4	14.9	2.83	
Grand Falls - Larch	46.1	21.1	15.7	3.00	31.6
Black spruce	43.5	17.5	13.2	2.28	
Millertown Jct. - Larch	50.4	20.4	15.3	2.52	43.2
Black spruce	58.0	18.9	13.9	1.76	

<sup>1/</sup> Source: Lavigne 1982.

were introduced to determine if other species were adaptable which would yield more fibre and consequently have greater economic value than the native species. Various species have been introduced from Scandinavia, western Europe, the USSR, Japan and western North America. Species chosen were from boreal or sub-boreal forests and it was thought that they would be reasonably adaptable to the Newfoundland climate. The species tested were primarily from the genera already native to Newfoundland - *Pinus*, *Picea*, *Larix* and *Betula* (Hall 1982). Locations of various test sites are shown in figure 4.

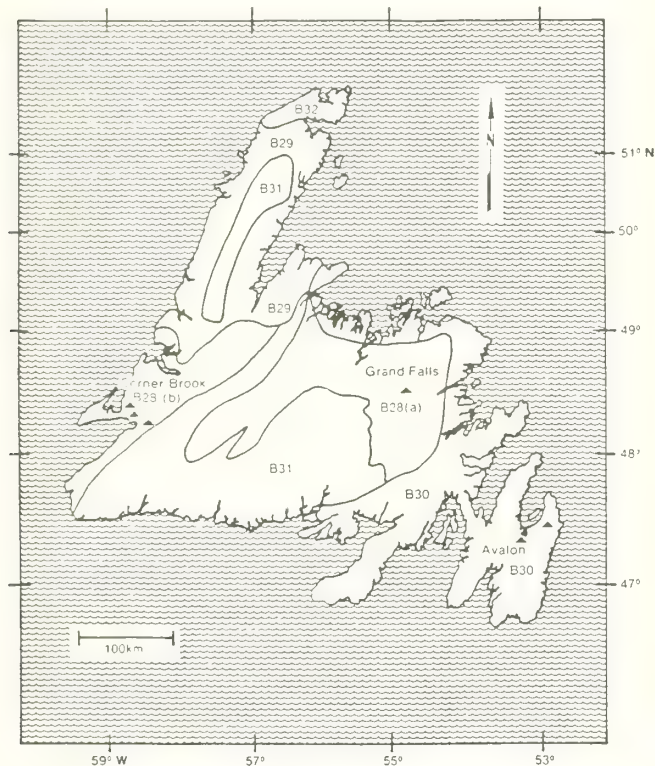


FIGURE 4  
NEWFOUNDLAND SHOWING FOREST SECTIONS  
AND LOCATION OF TEST PLOTS.

#### Western Newfoundland, Corner Brook Section

The largest species trial is located at Bottom Brook in western Newfoundland and is now nineteen years old. The plantation is on a rich mixedwood cutover which was burned after clearcutting in 1966. Several other exotics were planted on the site; the fastest growing of them grew at a similar rate as black spruce (Hall 1982). When the larches are compared to planted black spruce or white spruce or the exotic red spruce (*P. rubens* Sarg.), it is evident that they are superior in height growth and yield per tree dry matter production (table 3). Best growth was achieved with Japanese larch (*L. kaempferi* (Lam.) Carr.) followed by European larch (*L. decidua* Mill.). Variation within the seedlots were large with the tallest trees as much as 2 m taller than the mean for the plot. Some of the differences may be due to competition from natural regeneration of white birch which was present for a few years after planting. Both larch species have high within-provenance variability which could be exploited in a tree improvement program (Cook 1966).

Other trials in western Newfoundland have shown similar trends. A trial on a ploughed peat bog after 15 years from seed also shows Japanese larch to be outgrowing all other species; native black spruce, exotic Scots pine (*Pinus sylvestris* L.), Sitka spruce (*P. sitchensis* (Bong.) Carr.) and Norway spruce (*P. abies* L.). The height of Japanese larch averaged 2.35 m, the pine 1.31 m and the spruces less than 1 m (Hall 1982). The severe exposure of the site restricted growth rates but the larch was by far the most successful species.

Another trial on a cutover at higher elevation (365 m) and exposed to onshore winds consists of a species trial of native larch, Japanese larch, Siberian larch (*L. sibirica* Ledeb.) and hybrid larch (*L. eurolepis* Henry). At ten years from seed the hybrid larch (2.0-2.2 m) is significantly better than all other species with the Japanese larch and native larch at about the same height (1.7 m) (Hall 1984, in press).

Table 3--Comparison of yield of native and exotic larches and spruce in western Newfoundland

Species	Seedlot No.	Origin	Average total		Yield per tree (kg dry matter)
			Height (m)	Diameter (cm)	
Japanese larch	129	Germany	6.51	11.4	24.0
" "	130	"	6.74	10.8	22.8
" "	139	Honshu, Japan	6.96	12.1	27.8
European larch	102	Central Europe	5.60	10.1	17.8
	134	Germany	6.24	10.1	19.2
Larch	27	Eastern Nova Scotia	5.88	7.6	11.1
Black spruce	59	Central Newfoundland	3.73	5.7	7.7
White spruce	24	Eastern Nova Scotia	3.48	5.8	6.0
Red spruce	26	Central New Brunswick	4.19	6.8	10.4

1/ All larch yields calculated using larch (*L. laricina*) equations, red spruce yield calculated using black spruce equations (Lavigne 1982).

Table 4--Comparison of yield of native and exotic larches and black spruce in central Newfoundland

Species	Seedlot No.	Average Total		Yield per tree (kg dry matter)
		Height (m)	Diameter (cm)	
Japanese larch	129	4.31	6.6	6.3
" "	130	4.56	6.9	7.2
European larch	102	3.24	4.2	2.2
" "	134	3.11	4.8	2.7
Larch	27	5.72	7.2	9.7
Black spruce 1/	-	4.70	7.5	10.6

1/ Natural regeneration on the site was measured for comparison.

Larches have therefore consistently outgrown native spruces in these tests in western Newfoundland. Japanese larch shows considerable promise as an exotic and there is the possibility that other species and or hybrids may also have promise.

#### Central Newfoundland, Grand Falls Section

One species trial, also 19 years old, is represented in central Newfoundland. This plantation was established on a site which had been clearcut, then burned by wildfire in 1961, six years before planting commenced. The site rapidly became stocked with black spruce, white birch, trembling aspen and pin cherry (*Prunus pensylvanica* L.f.) with the wetter areas dominated by alders (*Alnus* spp.). Many of the exotic species soon became overtopped and only the planted pines and larches were able to maintain themselves in the stand. Native larch had the greatest height growth but the black spruce has the largest yield per tree (table 4). The comparison made is with black spruce natural regeneration as no planted spruce was available. Japanese larch is the fastest growing of the exotics and although trees have grown well (maximum height was over 7 m which was taller than any of the black spruce), the average height is less than that of the native larch. It is not possible to determine if the slower growth rate of the exotic larches is due to species differences or to effects of variable degrees of competition. Further testing will be needed to assess the potential of larch growing on similar sites.

#### Eastern Newfoundland, Avalon Section

A third plantation also 19 years from seed was established on a clearcut balsam fir site near St. John's. The dense balsam fir on the site suppressed most of the exotics except for the larches which outgrew it (Hall 1982). All larches outgrew native black spruce. Among the larches the European and native larch grew at about the same rate with the Japanese larch slightly superior to both (table 5). It is risky to extrapolate from small amounts of data such as these but there is at least a good indication that larches have reforestation potential in eastern Newfoundland too.

A second plantation was established on a barren land site on the Avalon Peninsula which had not been forested previously. Native larch was planted along with black spruce, white spruce, Scots pine and Jack pine (*P. banksiana* Lamb.). (Jack pine though a common boreal species is not native to Newfoundland.) After fifteen years the larch had outgrown the spruces by a wide margin (4.1 m compared to 1.2 m) (Hall 1982). The pines were intermediate with the Jack pine outgrowing the Scots pine (3.3 m compared to 2.7 m). The performance of larch on this site suggests that it has considerable potential for afforesting barren lands - certainly more so than black spruce or white spruce.

#### SILVICULTURAL IMPLICATIONS

1. In natural stands larch outgrows black spruce and produces more dry matter annually than does black spruce.
2. In planted stands larch has outgrown black spruce in most tests. Exotic larches especially Japanese larch and hybrid larch have outgrown native larch and spruce.

Table 5--Comparison of yield of native and exotic larches and black spruce in eastern Newfoundland.

Species	Seed lot no.	Average height (m)	Total diameter (cm)	Yield per tree (kg dry matter)
Japanese larch	129	3.78	6.3	5.8
"	130	4.38	7.7	9.6
"	139	3.84	6.1	5.6
European larch	102	2.93	5.7	4.0
"	134	3.54	5.6	4.5
Larch	27	3.54	5.9	4.9
Black spruce	25	2.47	3.2	3.2



3. The wide tree to tree variability in growth, development and wood quality in native and exotic larch means that there is an excellent opportunity to enhance productivity by selection and breeding (Loo et al. 1982, Park and Fowler 1983). Significant gains can also be made through inter-specific hybridization.

4. Results obtained in Newfoundland are consistent with those obtained elsewhere (Cook 1966, Vallée 1982). It is therefore with some assurance that they are recommended for inclusion in reforestation programs.

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## BOREAL ENERGY PLANTATION R & D WITH SALIX SPECIES

Alexander Robertson

**ABSTRACT:** In the last decade short-rotation willow plantations have become an attractive, high-yielding, biomass energy source in cool climatic regions. Preliminary results at Pasadena, Newfoundland show that  $28.5 \text{ t DM/ha}^{-1}/\text{yr}^{-1}$  with an energy equivalent  $513 \text{ GJ/ha}^{-1}$ , can be achieved in the boreal forest region. While high yields are expected in the more productive forest areas of Newfoundland, the paper stresses the need for biogeographical and biometeorological research that will examine the fundamental problems of establishing energy plantations in areas characterized by thin soils and a high mean annual wind speed.

### INTRODUCTION

Both Federal and Provincial Government policies in Canada advocate the use of forest biomass as a major renewable energy source. These policies create an obvious need for a sustained fuelwood management program to ensure continued and reliable sources of forest biomass. Implicit in such a program are the socio-economic benefits through the expansion of a specialized forest biomass industry and spin-off technologies.

As a result of these policies the use of fuelwood has increased dramatically in the last decade. In Newfoundland, for example, there was 168% increase in fuelwood consumption in 1983. Of the 3 million  $\text{m}^3$  of wood harvested on the Island, fuelwood accounts for roughly 25% (Northlands 1984a). The pulp and paper industry in Newfoundland utilized

approximately 50 000  $\text{m}^3$  of fuelwood (van Nostrand pers. comm.) and households consumed the remaining 700 000  $\text{m}^3$ . Overexploitation of the forests for household fuelwood in 'non-commercial' zones has become a serious problem in Newfoundland. The problem is especially critical on the Avalon Peninsula where the annual allowable cut (AAC) is 112 000  $\text{m}^3$  and in 1983 the fuelwood consumption alone was estimated at 196 000  $\text{m}^3$  (Northlands 1984b). Also, the forest has deteriorated to a patchwork of immature stands (Wilton 1984) which cannot meet future demand for fuelwood due to the long rotation age required for coniferous forests to reach merchantable volumes.

To alleviate the pressure on existing forest resources, short rotation energy plantations offer an alternative source of biomass energy. This paper discusses a developing boreal energy plantation research and development project based on willow coppice.

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## WILLOWS AS ENERGY BIOMASS

In terms of economic and environmental resilience willow energy plantations have a distinctive advantage over coniferous boreal forest and that is their high yields at an early age. Also, willow plantations can be established with ease from cuttings and harvested repeatedly on a 2-3 year rotation with a minimal energy input.

Because willows (*Salix*) is a predominantly northern genus, with a wide ecological amplitude and high genetic variability, they are admirably suited to cool, northern climates. Very few, if any, willows are strictly aquatic; the majority of species are to be found on moist, well-drained alluvial soils. Most are pioneer species on unstable or disturbed sites; in fact, the more common species are best known as ruderals along roadside embankments and abandoned farmlands.

In Eurasia, willows have been widely cultivated since early Greek times for fuelwood, construction manufacturing, pharmaceuticals, amenity planting, erosion control and, more recently, for short-rotation energy plantations (Robertson 1984a). Apart from ornamental planting and shelterbelts, willows have not been widely cultivated in North America.

In Newfoundland, research to evaluate willows for agroforestry and community shelterbelts began in 1981. This included the collection and acquisition of willow clones in Europe and eastern North America. To date, about 180 clones have been acquired. The collection represents clonal material that could be adapted to a broad range of sites in Newfoundland. These sites range from comparatively sterile sand dunes and disused gravel pits; rich, well-drained alluvial soils; poor, shallow and stony soils characteristic of barren regions; and drained peatlands. In 1982, under the ENFOR (Energy From The Forest) programme administered by the Canadian Forestry Service, emphasis shifted to the potential of willows for biomass energy and the project was broadened to reflect the full scope of research and development necessary for establishing economically viable energy plantations. Consequently, preliminary screening has concentrated on clones which have potential on medium quality forest cutovers in central and eastern Newfoundland where there is a reasonably good chance of success and, of course, where there is an existing demand for fuelwood in the form of wood chips.

## YIELDS

The preliminary screening of clones is being conducted at the Canadian Forestry Service Nursery at Pasadena, western Newfoundland. The climate and soils offer the best growing conditions on the Island. The soils are well-drained, sandy loam on a fluvio-lacustrine fan. The growing season usually begins about mid-May although it is not uncommon for buds to flush in late April or early May during brief warm, dry spells. Shoot elongation of most willow clones ceases at the end of October.

The willow clones at Pasadena are planted in stooling beds at a density of 30 000/ha<sup>-1</sup>. This is the same density planned for energy plantations. Although the project is still in its infancy, (which necessitates coppicing yearly to build up the planting stock), some preliminary results have been obtained to indicate the potential productivity. Table 1 shows the productivity and energy value from annual coppice of 2- and 3-year-old stools of selected clones. Figure 1 shows a 3-month-old stand of *Salix viminalis* shoots from 3-year-old stools which eventually produced 28.5 t DM/ha<sup>-1</sup>, or 513 GJ/ha<sup>-1</sup> (i.e., without foliage).



Figure 1.--A 3-month-old stand of *Salix viminalis* shoots from 3-year-old stools at Pasadena, Newfoundland. This stand eventually produced 28.5 t DM/ha<sup>-1</sup> with an energy value of 513 GJ (without foliage).

Although no data is yet available for coppicing on a 2-3 year rotation it is reasonable to assume that 15 t DM/ha<sup>-1</sup>/yr<sup>-1</sup> (270 GJ/ha<sup>-1</sup>/yr<sup>-1</sup>) is practically feasible under field conditions in western and central Newfoundland because of the similarity in climatic conditions. Elsewhere in Newfoundland, especially the Avalon Peninsula, characterized by poor soils and a high mean annual



Table 1--Productivity and energy value of 2- and 3-year-old stools of selected willow clones coppiced yearly in early spring prior to bud-burst at Pasadena, Newfoundland (based on a density of 30 000 stools/ha<sup>-1</sup>)

Species	Clone No.	Annual yield			
		2nd year stools		3rd year stools	
		t DM/ha <sup>-1</sup>	GJ/ha <sup>-1</sup>	t DM/ha <sup>-1</sup>	GJ/ha <sup>-1</sup>
<i>Salix viminalis</i>	082	13.4	241	28.5	513
<i>S. alba</i> (Italy)	5016	12.9	232	20.2	364
"	5017	7.9	142	24.0	432
"	5018	7.7	139	24.4	439
"	5019	4.6	83	8.2	148
<i>S. alba</i> (Romania)	5020	3.3	59	12.8	230
"	5021	2.7	49	10.5	191
"	5022	2.8	50	9.8	176
"	5023	7.0	126	15.8	284
<i>S. fragilis</i>	5004	12.8	230	21.0	378
"	5005	8.1	146	16.5	287
"	5010	6.0	108	21.0	378
"	5011	10.6	191	18.0	324
<i>S. nigra</i>	5002	9.5	171	13.5	243
"	5002	9.5	171	17.0	306
"	5009	8.7	157	9.0	162

wind speed (Robertson 1984b, Wilton 1984) productivity is difficult to estimate. In some of the sheltered and more fertile sites, e.g., in the Salmonier area, 10 t DM/ha<sup>-1</sup>/yr<sup>-1</sup> (180 GJ/ha<sup>-1</sup>/yr<sup>-1</sup>) may be possible.

#### R & D PRIORITIES

In 1984, funding by ENFOR increased considerably to enable the establishment of experimental plantations and expand the level of basic research. R & D currently underway include:

##### Plantation Establishment

Four sites in central and one in eastern Newfoundland are currently being developed for planting in 1985. The sites in central Newfoundland include an abandoned pasture and two recently logged areas. The site in eastern Newfoundland is located on farmland in an area that is characterized by drumlins. Since a biophysical assessment of these sites is still underway specific details are not yet available but will be published at a later date. Suffice to note that the three sites in central Newfoundland were chosen because of their proximity to existing wood chip users, i.e., the Abitibi Pulp and Paper Mill at Grand Falls and the Gander Regional Hospital. The site in eastern Newfoundland has two potential users, i.e., fuelwood for the Salmonier Correctional Institute and forage for the Salmonier Wildlife Park.

#### Biogeographical Research

To date biogeographical research has concentrated on baseline studies on the ecology, distribution and utilization of willows. A review of world literature shows the biogeography of willows in Eurasia is well known, but has not been widely studied in North America except as a shelterbelt species on the prairies. The current emphasis of biogeographical research is to concentrate on the silvics of native and exotic willows which may have some potential in boreal agroforestry. Apart from the need to understand more fully the biology and ecology of willows, there is a particularly urgent requirement for studies on clone/site matching, development of biomass equations, optimum stand densities, control of insects, diseases and development of silvicultural techniques.

#### Biometeorological Research

The climate of Newfoundland is not easily divisible into homogenous units because of its insular nature, and also because it lies in the path of almost every major cyclone that tracks across the continent and up the eastern seaboard. The combination of unsettled weather associated with frontal systems and the complex topography of the Island means that comparatively small changes in elevation and aspect result in considerable differences in the gradients of atmospheric properties, most notably, wind. These differences are often reflected by a sharp contrast in biomass

productivity. Research on the atmospheric parameters which control biomass productivity is of primary concern in the siting of energy plantations. However, a major obstacle to microclimate studies, particularly the effects of wind on biomass production, is the technical and economic constraints which preclude effective and efficient measurement of climatic variables.

Robertson (1984b) used tamarack as a biological indicator to estimate the spatial and temporal variation of mean wind speed and direction in complex, forested terrain. The relationship between crown deformation and mean wind speed ( $\bar{u}$ ) is expressed by the equation

$$\bar{u} = -5.96 + 10.0D - 1.7D^2 \quad (R^2 = 0.86)$$

D is the deformation ratio computed from

$$D = B + \frac{A}{450}$$

where B =  $\frac{\text{mean branch extension leeward}}{\text{mean branch extension windward}}$

A = Angle of trunk inclination

On reasonably level terrain the mean windspeed could also be estimated from the compression indice from the equation

$$\bar{u} = 34.4 - 43.1C + 15.8C^2 \quad (R^2 = 0.53)$$

where C =  $\frac{\text{Tree ring width leeward of pith}}{\text{Tree ring width windward of pith}}$

Using these indices it was found that mean wind speeds in excess of  $6 \text{ ms}^{-1}$  seriously retards tree growth and that siting of energy plantations should be avoided under these conditions. The study also showed that summer southwesterly winds are the main cause of tree deformation, therefore, in areas where mean wind speeds exceed  $5 \text{ ms}^{-1}$ , the orientation of plantations should be of prime consideration.

Energy balance studies to determine the efficiency of energy storage of selected willow clones under different climatic conditions is an important consideration. The energy balance is defined by the equation

$$Q^* = Q_H + Q_E + \Delta Q_P + \Delta Q_S + Q_A$$

where  $Q^*$  = Net radiation flux density ( $\text{Wm}^{-2}$ )

$Q_H$  = Turbulent sensible heat flux density

$Q_E$  = Turbulent latent heat flux density

$\Delta Q_P$  = Rate of biochemical heat storage

$\Delta Q_S$  = Rate of physical heat storage

$Q_A$  = Horizontal energy transport in air per unit horizontal area.

Although our primary interest is the  $\Delta Q_P$  term, i.e. theoretically the maximum amount of biomass a particular area can produce, the  $Q_A$  term is undoubtedly the most important in the Newfoundland context since wind is a major constraint to plant productivity. Currently, the methodology for studying the energy budget of plantations is being developed.

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COMPARATIVE PRODUCTIVITY OF SEEDED, NATURAL AND PLANTED REGENERATION  
FOLLOWING VARIOUS SITE TREATMENTS IN WHITE SPRUCE CLEARCUTS

R.G. McMinn

INTRODUCTION

Forest regeneration options are numerous. Stands may be restocked by natural regeneration, direct seeding or planting. The multiplicity of nursery stock types and site treatment methods increases the number of alternatives.

Regeneration strategy decisions depend on the interplay between two major factors - the productivity and the cost of regeneration options. This study indicates the relative productivity of a number of options.

The occurrence of seeded, natural and planted regeneration adjacent to each other in three clearcut sites 60 km east of Prince George, British Columbia, provided an opportunity to compare early white spruce (*Picea glauca* (Moench) Voss) growth rates following different methods of stand establishment. Several site treatment alternatives could be compared in each site. All sites had dense competing vegetation. Plantations ranged in age from 8 to 13 years.

METHODS

The height and diameter at groundline of the 10 tallest trees representing the regeneration options present in each site were measured and stem

volume calculated. Data were analyzed by the Student-Newman-Keuls multiple range test. The age of planted trees was obtained from plantation records. The age of natural regeneration was determined by counting the rings in stem discs cut at ground line. For purposes of comparison, heights and diameters of naturally regenerated trees were adjusted to remove differences from adjacent planted trees due to difference in age. Heights were reduced by the length of internodes added during the years that naturally regenerated trees exceeded the age of planted trees. Similarly, diameters were reduced by the width of extra rings. The age of natural regeneration may have been underestimated because the earliest rings were difficult to differentiate. Underestimation of age would overestimate the size of natural regeneration. The growth of stock in the two direct seeded plots may have been reduced by crowding. Even 13 years after seeding, more than 20 trees remained in each one square meter lot.

Sites had been prepared by scarifying, mixing or inverting, or had been left untreated. Scarifying with a bulldozer blade scalped off vegetation, surface organic matter and uppermost mineral soil to expose subsurface soil for planting or as a seedbed. In the mixing treatment, vegetation and surface organic matter were thoroughly mixed with the underlying mineral soil to form a new surface layer. Although this layer was enriched with organic matter, it was essentially mineral in consistency. The inverting treatment consisted of turning 25 cm<sup>2</sup> patches of soil upside down in the 15 cm deep

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hole left by digging out the patch. The original surface organic matter was thus placed upsidedown below the new surface layer of mineral soil which had originally been subsurface. Competing vegetation was adequately controlled by all treatments, at least for the first year.

## RESULTS AND DISCUSSION

The data (Tables 1 - 4) show that for the period studied planted stock outproduced seeded or natural regeneration by three (Table 2) to several hundred fold (Table 4).

Treatments that retained the fertility of surface organic matter available to seedlings (mixing and inverting) produced significant gains in productivity compared to scarifying. Scarifying deeply enough to completely control competing vegetation by removing its roots deprives seedlings of the fertility of uppermost layers. Seedling productivity in lightly scarified areas where some surface material remained was somewhat better than that of adjacent seedlings where scarification was deep (Table 1). Shallow scarification, however, generally provides inadequate control when competing vegetation is vigorous and dense (McMinn 1982a).

Retention of the fertility of surface organic matter by leaving the site untreated is not a viable option for seeding or natural regeneration (Dobbs 1972). Germinants rarely survive in undisturbed surface organic matter. Some grains were recorded with seedbeds formed by mixing rather than scarifying (Table 4).

Table 1. -Stem height, diameter and volume of white spruce natural regeneration and planted Styroplug 2<sup>1</sup> seedlings after 8 growing seasons following various site treatments in a clear-cut with a sandy soil (Site 1).

Regeneration method Site treatment	Height <sup>2</sup> cm	Diameter cm	Volume <sup>3</sup> cm <sup>3</sup>
Natural regeneration			
Deep scarifying <sup>6</sup>	56a <sup>5</sup>	0.9a	13a
Light scarifying	101b	1.5b	59b
Planting			
Deep scarifying	203c	3.2c	572c
Mixing	241d	4.1d	118d

- <sup>1</sup> Seedlings grown in containers with cavity volume of 2 in<sup>3</sup> (40 cm<sup>3</sup>).
- <sup>2</sup> Mean heights and diameters (at ground line) of 10 trees measured.
- <sup>3</sup> Height times one-third cross sectional area at ground line.
- <sup>4</sup> All surface organic matter and uppermost mineral soil removed.
- <sup>5</sup> Values in each column differ significantly (p = 0.05).
- <sup>6</sup> Some surface organic matter remaining.
- <sup>7</sup> Mixed layer 15 cm deep produced by Madge Rotoclear.

The largest difference between seeded and planted stock occurred with large stock planted in untreated areas (Table 4). Standard stock (eg 2+0 bare root or Styroplug 2 seedlings) generally grows poorly when subject to competition from dense vegetation (McMinn 1982b). Retention of the fertility of surface organic matter by leaving sites untreated would seem most feasible when superior stock is outplanted.

The divergent growth trends shown in Figure 1 provide evidence that early differences in productivity may increase with time. If such trends continue, high early productivity might predict reduced time to merchantable size. With a sustained yield policy, shortening time between stand establishment and harvesting would mean larger annual allowable cut. While this may be unimportant when poor markets reduce current need below allowable cut, if demand rises in future, an increase in allowable cut would be desirable.

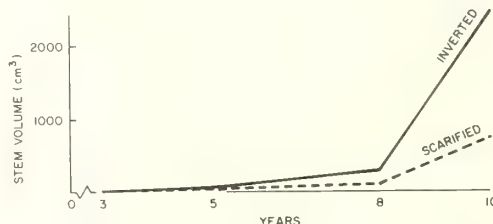


Figure 1. --Stem volume for the first 10 growing seasons of Styroplug 2 white spruce seedlings in planting spots prepared by scarifying and inverting treatments (Site 2).

Table 2. -Stem height, diameter and volume of white spruce natural regeneration and planted Styroplug 2<sup>1</sup> seedlings after 10 growing seasons following various site treatments in a clear-cut with a silt loam soil (Site 2).

Regeneration method Site treatment	Height <sup>2</sup> cm	Diameter cm	Volume <sup>3</sup> cm <sup>3</sup>
Natural regeneration			
Scarifying <sup>4</sup>	166a <sup>5</sup>	2.2a	223a
Planting			
Scarifying <sup>4</sup>	202b	3.6b	740b
Inverting	292c	5.5c	2408c

- <sup>1</sup> Seedlings grown in containers with cavity volume of 2 in<sup>3</sup> (40 cm<sup>3</sup>).
- <sup>2</sup> Mean height and diameter (at ground line) of 10 trees measured.
- <sup>3</sup> Height times one-third cross sectional area at ground line.
- <sup>4</sup> All surface organic matter and uppermost mineral soil removed.
- <sup>5</sup> Values in each column differ significantly.

Table 3. -Stem height, diameter and volume of white spruce natural regeneration and planted Styroplug 2<sup>1</sup> seedlings after 11 growing seasons following various site treatments in a clear-cut with a silt loam soil (Site 2).

Regeneration method Site treatment	Height <sup>2</sup> cm	Diameter cm	Volume <sup>3</sup> cm <sup>3</sup>
Natural regeneration			
Scarifying <sup>4</sup>	189a <sup>5</sup>	2.5a	321a
Planting			
Scarifying <sup>4</sup>	293b	5.1b	2 067b
Mixing	331c	6.5c	4 030c

- <sup>1</sup> Seedlings grown in containers with cavity volume of 2 in<sup>3</sup> (40 cm<sup>3</sup>).
- <sup>2</sup> Mean heights and diameters (at ground line) of 10 trees measured.
- <sup>3</sup> Height times one-third cross sectional area at ground line.
- <sup>4</sup> All surface organic matter and uppermost mineral soil removed.
- <sup>5</sup> Values in each column differ significantly.
- <sup>6</sup> Mixed layers 20 cm deep produced by Howard Rotovator driven by p.t.o. of farm tractor.

#### CONCLUSIONS

The data from this study indicate that:

1. planting results in much higher early productivity than either seeding or natural regeneration;
2. with standard stock, early productivity may be doubled or trebled by methods of site treatment that retain the fertility of surface organic matter available to seedlings (mixing and inverting), as compared to removal of surface organic matter by blade scarifying;
3. with superior stock, able to withstand the effects of competing vegetation, retention of surface organic matter by leaving the site untreated may give the highest productivity;
4. if the early increases in productivity indicated by this study were maintained, annual allowable cut would be increased.

Table 4. -Stem height, diameter and volume of white spruce seeded and natural regeneration and planted stock after 13 growing seasons following various site treatments in a clearcut with a silt loam soil (Site 3).

Regeneration method Stock/Site treatment	Height <sup>1</sup> cm	Diameter cm	Volume <sup>2</sup> cm <sup>3</sup>
Seeded <sup>3</sup>			
Scarifying <sup>4</sup>	94a <sup>5</sup>	1.4a	54a
Mixing	114b	1.7ab	90ab
Natural regeneration			
Mixing <sup>6</sup>	114b	1.9b	115b
Planting			
2+0 <sup>7</sup> / Scarifying <sup>4</sup>	346c	6.1c	4 552c
2+0 <sup>8</sup> / Mixing	473d	8.3d	9 082d
2+1 <sup>9</sup> / Untreated	510 e	9.3e	12 106e
Styroplug 8 <sup>9</sup> / Untreated	536 e	10.3f	15 702e

- <sup>1</sup> Mean heights and diameters (at ground line) of 10 trees measured.
- <sup>2</sup> Height times one-third cross sectional area at ground line.
- <sup>3</sup> In a one square meter plot.
- <sup>4</sup> All surface organic matter and uppermost mineral soil removed.
- <sup>5</sup> Values in each column followed by the same letter do not differ significantly (p = 0.05).
- <sup>6</sup> Mixed layer 7 cm deep produced by 10 HP garden rotovator.
- <sup>7</sup> Bare root seedlings.
- <sup>8</sup> Bare root transplants.
- <sup>9</sup> Seedlings grown in containers with cavity volume of 8 in<sup>3</sup> (125 cm<sup>3</sup>) for two growing seasons.

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## ECONOMICS OF PRECOMMERCIAL THINNING IN JACK PINE

C. Rodney Smith, J. D. Johnson and L. F. Riley

**ABSTRACT:** The economics of precommercial thinning in jack pine (*Pinus banksiana* Lamb.) for sawlog production is analyzed with data produced to date from two precommercial thinning trials undertaken in northern Ontario in 1970. Overstocked conditions in the unthinned stands make diameter and density projections imprecise; however, preliminary indications are that neither of these two thinnings will provide attractive returns. Higher densities in the unthinned stands at rotation more than offset the economic contribution of the higher average diameters of the thinned stands. Further measurements are required to predict the development of the unthinned stand more precisely. Optimum estimates of diameter and density development indicate that the stand thinned at age 9 years will provide a positive return to investors requiring a real rate of return of 4%. The stand thinned at age 9 years yields a higher return than the stand thinned at age 22 years because of the high treatment cost of the 22-year-old thinning.

### INTRODUCTION

One of the potential solutions to Canada's decreasing timber supply is the practice of more intensive forest management to improve the quality and volume per hectare (Reed and Assoc. 1978). By redistributing growth to the remaining trees, precommercial thinning promotes the growth of larger and more valuable trees on shorter rotations (Fasick 1965). Intensive management practices such as precommercial thinning must, however, be operationally practicable and economical, and must yield desirable biological results. Unfortunately, few thinned

stands have been assessed at maturity, the only time when the impact of thinning can be fully determined (Riley 1973).

The purpose of this paper is to set out a range of criteria for evaluating the economics of thinning for sawlog production in overly dense jack pine (*Pinus banksiana* Lamb.). Analyses are presented in case study form and are based primarily on results from operational trials conducted in 1969-1970 by the Great Lakes Forest Research Centre in northern Ontario. Results with regard to the efficiency and costs of various thinning tools and techniques used in the trials are described in Riley (1973). Ten-year growth response data are presented in Smith (1984). It is emphasized that results from the case study are interim in nature. Long-term results from this and other studies will facilitate the construction of more accurate economic models.

### DESCRIPTION OF CASE STUDY TRIALS

Stands aged 9, 22 and 33 years (age classes I,

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II, and III, respectively) were treated. (Data from the age class III study have, for the most part, been excluded from the analyses.) All sites are typical for jack pine. Site and stand conditions before treatment are presented in tables 1 and 2 (Riley 1973).

All thinning work was carried out on a piecework basis. Trees were individually spaced. Operational data including the tools used and production and cost figures are provided in table 3 (Riley 1973).

Stand stocking and density of jack pine, and average height and diameter of selected co-dominant and dominant potential crop trees immediately after treatment and 10 years after treatment, are presented in table 4 (Smith 1984). Complete stand tables and, therefore, estimates of basal area and volume are not available at this time. An understorey of black spruce (*Picea mariana* [Mill.] B.S.P.) developed in the stands but jack pine remained clearly dominant after 10 years (Smith 1984).

## GROWTH PROJECTIONS

### Height and Diameter

The effect of thinning on height growth is insignificant, both minor increases and decreases having been reported (Wilson 1951, Cayford 1964, Steneker 1969, Benzie 1983, Smith 1984). On the other hand, diameter has been shown to increase as a result of thinning over a wide range of age classes (Wilson 1952, Cayford 1961, 1964, Benzie 1983).

In the Ontario case study, the projected incremental increase in average diameter of the selected crop trees in the thinned age class I and II stands is conservatively estimated to be marginal at approximately 0.50 cm by age 90 years (Smith 1984). There is reason to believe that significantly higher gains from thinning may be possible.

In the first place, diameter growth in the unthinned stands may have been overestimated. Numerous authors state that overly dense stands of jack pine tend to stagnate (Gevorkiantz 1947, Roe and Stoeckeler 1950, Wilson 1952, Skilling 1957, Fowells 1965, Steneker 1969, Bella 1974, and Benzie 1977). Estimates of densities at which stagnation may occur are unclear or vary widely (e.g., from 5,000 [Benzie 1977] to 25,000 [Fowells 1965] sapling-size [5 to 12 cm DBH] stems per ha). The unthinned stands in the Ontario case study fall within this range (Smith 1984) and there is evidence of stagnation. In the age class III control stand (5,900 stems per ha at age 33 years), the periodic annual increment (PAI) in breast height diameter (DBH) between the ages of 28 and 43 years was one-third that of Plonski's (1974) normal, fully stocked stand (i.e., 0.1 cm versus 0.3 cm, respectively). Differences may in fact be even more pronounced, since Plonski's figures are based on stand averages while the case study

values are from dominant and codominant crop trees only.

In the second place, more favorable responses may have been achieved if the stands had been thinned to lower densities (with wider spacings). It has been shown that, generally, the heavier the thinning the greater the response (Cayford 1961, 1964, Bella and DeFranceschi 1974b, Benzie 1983). In both the age class I and the age class II stands, spacing failed to meet the prescribed values (i.e., 1.6 m versus 1.8 m in the former and 2.2 m versus 2.4 m in the latter).

For the purposes of analysis, it is assumed that DBH projections in the thinned stands will be at least as good as shown in Smith (1984) (i.e., about 20 cm DBH at age 90 years in both the age class I and the age class II stands). The 0.5 cm DBH advantage of the thinned over the unthinned stands mentioned previously may be taken as a minimum. As a maximum, it may be reasonable to expect a difference of 3.0 cm. Therefore, average DBH in the unthinned stands at 90 years may be as high as 19.5 cm and as low as 17.0 cm.

### Density

Density in the thinned stands at rotation may be approximated by using variable density growth and yield tables developed by Evert (1976) from permanent sample plots maintained by American Can of Canada Ltd. and Kimberley Clark of Canada Ltd. in north central Ontario. Yields are presented for natural stands which had variable numbers of trees at age 30 years. The height/age and, therefore, site relationships are very similar to those of Plonski (1974). Stand age, density and height are required to use Evert's model.

Projections were made from ages 30 and 35 years in the age class I and the age class II stands, respectively, to age 90 years. Densities at ages 30 and 35 years were determined from simple projections of the 10-year growth data. In the absence of complete stand information, Plonski's mean stand height for site class II was used. Densities at age 90 years were determined to be 1010 and 829 stems per ha for the age class I and the age class II thinned stands, respectively (table 5).

Evert's tables are based on a range of densities from 620 to 3700 stems per ha at age 30 years. These densities are considerably lower than the densities of the unthinned stands in the case study. For this reason, Evert's tables could not be used. At this point it is not possible to predict the extent to which mortality will affect density at rotation in the unthinned stands.

### Volume

The critical question remains as to whether

Table 1. Site descriptions

Age class	District	Forest section <sup>1/</sup>	Site class <sup>2/</sup>	Moisture regime <sup>3/</sup>	Soil
I ( 9 yr )	Gogama	B7	2	1	medium sand
II (22 yr)	Chapleau	B7	2	2	fine sand

<sup>1/</sup> Rowe (1972)<sup>2/</sup> Plonski (1960)<sup>3/</sup> After Hills (1952)Table 2. Stand descriptions (before treatment)<sup>1/</sup>

Age class	Stocking %	Density (trees/ha)	Avg. DBH (cm)	Avg. ht (m)	Stand origin
I ( 9 yr )	99 <sup>2/</sup>	13,170	2.5	1.8	scarification and aerial seeding
II (22 yr)	96 <sup>3/</sup>	10,428	5.1	5.8	wildfire

<sup>1/</sup> Values converted from Imperial to S.I. units.<sup>2/</sup> Percentage of 4-m<sup>2</sup> quadrats with at least one tree.<sup>3/</sup> Percentage of 6-m<sup>2</sup> quadrats with at least one tree.Table 3. Operational data<sup>1/</sup>

Age class	Treatment	Treated area (ha)	Prescribed spacing (m)	Average spacing after treatment (m)	Labor (man-hours/ha)	Cost/ha <sup>2/</sup> (1970 dollars)
I ( 9 yr )	hand tools	5.0	1.8	1.6	18.93	45.42
	brush saws	11.6	1.8	1.6	9.71	39.33
II (22 yr)	hand tools	0.6	2.4	2.2	67.06	234.72
	chainsaw	2.0	2.4	2.2	35.58	177.91

<sup>1/</sup> Values converted from Imperial to S.I. units.<sup>2/</sup> Including equipment, materials and supplies.

Table 4. Stocking, density, height and diameter response after 10 years

Age class	Treatment	Stocking (%)		Density (trees/ha)		Average ht (m)		Average DBH (cm)	
		After treatment	10 years	After treatment	10 years	After treatment	10 years	After treatment	10 years
I ( 9 yr )	thinned	80	76	3,906	3,412	1.8	6.7	2.5	8.4
	control	--	84	--	13,232	1.8	7.0	2.5	6.6
II (22 yr)	thinned	86	80	2,066	1,858	7.0	11.6	8.2	12.4
	control	--	98	--	8,303	5.8	11.0	8.1	10.1

Table 5. Projected densities of thinned stands

	Age (yr)	Height (m)	Density >2.5 cm DBH (trees/ha)
Age class I	30	10.3	3100
	90	22.0	1010
Age class II	35	11.8	1201
	90	22.1	829
Average projected density (age 90)			
$= \frac{1010 + 829}{2} = 919.5 \text{ trees per ha}$			

increased diameter growth from thinnings will be able to compensate for the initial reduction in total number of stems. Estimates of total volume production are difficult. Cayford (1961, 1964) reports that 32- and 40-year results from thinnings in Saskatchewan and Manitoba at age 18 and 10 years, respectively, did not result in increased total volume production. However, Benzie (1983) reports that 30-year results from thinnings in the Lake States at age 5 years show greater total volume production in stands thinned from 1.2 to 2.4 m. Cayford (1961) reports that in the above-mentioned stand thinned at age 10 years, a 6-ft (1.8-m) spacing increased sawlog volume by 1200 bd ft per acre (7.0 m<sup>3</sup>/ha). In the stand thinned at 18 years, sawlog volumes were increased from 435 to 1337 bd ft per acre (2.5 and 7.8 m<sup>3</sup>/ha) at age 50 years with the greatest increase arising from thinning to 5- and 6-ft (1.5- and 1.8-m) spacings (Cayford 1964). Bella and DeFranceschi (1974a) estimate that precommercial thinning may be as much as double board foot (sawtimber) production by final harvest and the increase may be as high as 3000 bd ft per acre (17.5 m<sup>3</sup>/ha) on average sites and perhaps twice that amount on good sites. (As data are lacking, the latter is an estimate only.)

Therefore, on the basis of results from outside Ontario, it may be reasonable to expect an increase of at least 6.0 m<sup>3</sup>/ha of board foot volume as a result of thinning. This could be as high as 17.5 m<sup>3</sup>/ha and, very optimistically, as much as 35.0 m<sup>3</sup>/ha.

#### Rotation Age

If we assume that average DBH is used to establish time of harvest, we can expect that increased growth in the thinned stands will result in a reduction of at least 10 years in rotation age (Smith 1984). It is difficult to predict whether an earlier harvest will be desirable with respect to merchantable volume. Bella and DeFranceschi (1974a) are optimistic in stating that if the criterion is a specified volume of merchantable yield, medium intensity precommercial thinning may shorten rotation age by about 10 years.

#### ECONOMIC CONSIDERATIONS

Estimates of the value of the thinned stand must be compared with similar estimates for the control stand, in order to assess the effectiveness of the thinning treatment. Any incremental revenue or reduced costs that can be attributed to the treatment will provide a measure of the future economic worth of the treatment. Then, by accounting for initial treatment cost and the time value of money, an assessment of the overall economic worth of the treatment can be made. It is assumed that both the controls and the treated stands are being managed for sawlogs.

#### Incremental Revenue

Lumber recovery estimates for jack pine tree lengths as measured by butt diameter were provided by a local sawmill. Recoverable sawn volumes were then apportioned into lumber grades by butt diameter, with percentages developed for jack pine by Flann and Petro (1964) being used. With the best estimates for future diameters of the thinned and unthinned stands (20.0 cm and 18.75 cm, respectively), and on the assumption that final densities of the thinned stands are 920 stems per ha and final densities of the unthinned stands are approximately 1000 stems per ha, projected incremental board-foot-volume-per-hectare is comparable to volume increments mentioned above in Bella and DeFranceschi (1974a) and Cayford (1964).

Total merchantable volume was estimated from recovery ratios also established by Flann and Petro (1964). The difference between total merchantable volume and sawn volume was assumed to be sold as pulp chips by the lumber manufacturer. Butt diameters were converted to DBH according to a relationship established by Alemdag and Honer (1977).

Appropriate unit prices were assigned to the sawn volumes by grade and to the pulp chips in order to generate an estimate of average revenue per stem by DBH in 1984 dollars. Wholesale prices of jack pine lumber by grade<sup>1/</sup> were adjusted by a projection of the 1984 jack pine selling price index<sup>2/</sup> with historical data being used to moderate any cyclical or seasonal attributes inherent in current prices. The latest estimates of pulp chip selling prices<sup>3/</sup> were inflated to 1984 dollars by using the pulp and paper selling price index<sup>2/</sup>. It is assumed that there will be no real changes in unit prices of

<sup>1/</sup> Anon. 1984. Selling prices to wholesalers reported by manufacturers. Knots and Slivers. May 25, 1984. Hearst, Ontario.

<sup>2/</sup> Statistics Canada. Industry price indexes. Catalogue No. 62-011. Monthly. March, 1984.

<sup>3/</sup> Statistics Canada. Pulp and paper mills. Catalogue No. 36-204. Annual. 1982.



the various products produced.

Figure 1 illustrates estimated revenue per tree by DBH. The use of density (stems per hectare) and average breast height diameter predictions for the thinned and control stands permits estimates of revenue per ha to be generated.

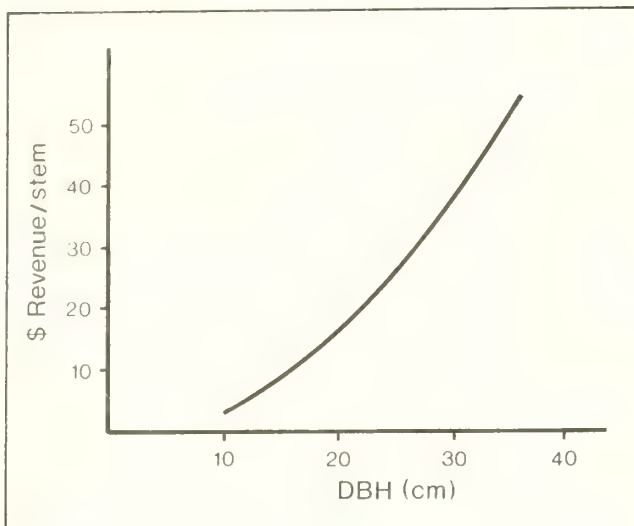


Figure 1.--Estimate of revenue per stem for jack pine in 1984 dollars.

It is assumed that no revenue is generated by the age class I or age class II thinning.

#### Incremental Harvesting Cost

It has been shown that unit harvesting costs vary inversely with diameter (Hannula 1971). Because the thinned stands are expected to yield stems with higher average diameters than the controls, the reduced harvesting costs should be considered a benefit directly attributable to the treatment at time of harvest.

The mechanization of woodlands operations has reduced the effect of stem diameter on unit harvesting costs. Previous studies in this area employed conventional cut and skid harvesting techniques and, therefore, likely overestimate the effect of log diameter on harvesting costs for mechanized systems. If we assume that the trend toward increased mechanization will continue, it would be appropriate to estimate the effect of stem diameter on logging costs under a fully mechanized system. It is assumed that diameter affects unit costs for only the felling, piling of stems and maneuvering in the stand. Methodology provided in a specific feller forwarder evaluation report by Legault (1976) was used to estimate cost per productive machine hour in 1984 dollars. Estimates of machine productivity as measured by individual tree volume in the Legault study and a volume diameter relationship established for jack pine

by Payandeh (1982) were used to estimate machine productivity (i.e., harvesting time per tree) as measured by average breast height diameter. Figure 2 illustrates estimates of harvesting cost per stem and harvesting cost per unit volume by breast height diameter.

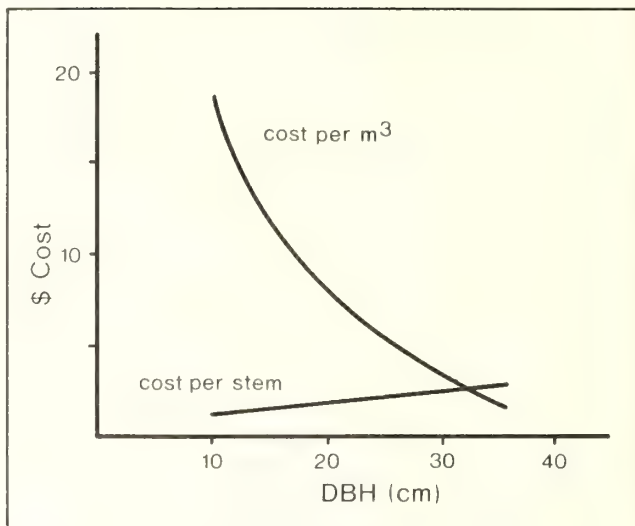


Figure 2.--Estimates of mechanical harvesting cost for jack pine in 1984 dollars. Cost to fell and load stems and to maneuver in stand only.

As with revenues, density and average diameter predictions can be used to estimate future harvesting costs for the thinned and control stands. It was assumed that real harvesting costs will not change throughout the life of the investment.

#### Other Production Costs

It is recognized that average stem diameter directly affects other unit production costs (i.e., roadside processing, transportation, milling); however, it is assumed for purposes of this analysis that in fully mechanized, efficient production systems, the present value of these effects would be negligible in view of the time periods involved and the limited magnitude of the diameter increment of the thinned stands over the unthinned stands.

#### Treatment Costs

It is useful to express treatment costs in 1984 dollars so that the analysis is relevant to forest managers today. It is assumed that the least expensive precommercial thinning treatments are employed (i.e., brushsaws in age class I, chain saws in age class II).

Treatment costs incurred in 1970 (see table 3) were inflated to 1984 dollars by using the Gross

National Expenditure Implicit Price Index<sup>4/</sup>. In 1970 the age class I thinning cost \$39.33 per ha (\$124.00 per ha in 1984 dollars). Similarly, the age class II thinning cost \$177.91 per ha in 1970 (approximately \$560.00 in 1984 dollars).

#### Other Benefits

If the demand for jack pine sawlogs equals or exceeds supply when the thinned stand is ready for harvest, and if the thinned stands contain more board feet per ha than the unthinned stands, the incremental volume produced from the thinned stand will provide the economy with incremental value-added through the sawmilling industry. This potential benefit is not included in the analysis because of the high degree of uncertainty involved.

#### ECONOMIC ANALYSIS

Only the incremental future value of the thinned stands over the controls can be attributed to the treatments. Density and average diameter projections can be used to estimate the incremental future value (i.e., additional revenue and reduced harvesting costs) of the thinned stands over the controls. This incremental future value must then be discounted to the present by using an appropriate discount rate in order to account for the cost of the invested capital. Finally, the initial treatment cost must be accounted for. Two methods commonly used to make investment decisions are employed--internal rate of return and net present value.

#### Internal Rate of Return (IRR)

The internal rate of return (IRR) is the specific discount rate that makes the net present value of an investment equal to zero. The investor can then compare his required rate of return with the calculated IRR. If the investor's cost of capital is lower than the IRR, the project will have a positive net present value. If the investor's required rate of return is greater than the IRR, the investment should not be undertaken. The IRR method is particularly useful for ranking investment opportunities.

Projections of stand densities in the thinned stands are possible; however, future densities of the control stands are uncertain. Measurements to date suggest that both controls are still overstocked and that natural thinning is progressing slowly. It is appropriate, therefore, to compare a range of possible control stand densities with a best estimate of density in the thinned stands under both the optimistic

(i.e., thinned stand average diameter of 20.0 cm and control stand average diameter of 17.0 cm), and conservative (i.e., thinned stand average diameter of 20.0 cm and control stand average diameter of 19.5 cm) diameter projections. From the case study (see table 5), it is estimated that at age 90 years the thinned stands will have a density of 920 stems per ha.

Table 6 illustrates IRR achievable under various control stand densities at age 90 years for the age class I and the age class II treatments.

A number of observations can be made from table 6. First, the investment does not appear to be an overly attractive one. Even under the most optimistic conditions, the real IRR is only 4.5%. Only an investor with an extremely low required rate of return would consider such an investment. Row et al. (1981) suggest that a real rate of return of 4% is appropriate for long-term forestry investments by the USDA. Private investors require even higher returns.

Second, should the density of the controls remain high, then even under the most optimistic diameter projections, returns are low. This is due to the fact that if densities of the controls remain high, even though the harvesting conditions would be higher and the revenue per cubic metre less because of the lower average diameters, the volume would be so much higher than in the thinned stand that the net present value per ha would be higher. The higher revenue per ha in the controls more than offsets the increased harvesting costs.

Finally, in spite of the greater time period involved, the 9-year-old thinning results in higher IRR than the 22-year-old thinning. This is due to the high treatment cost associated with the 22-year-old thinning.

#### Net Present Value

The net present value method uses a specific discount rate to calculate the present value of the revenues and costs associated with an investment opportunity. The discount rate is considered the minimum rate of return required for a particular type of investment. A positive net present value indicates a positive return after risk and financing costs have been accounted for. A negative net present value would indicate that the investment opportunity should not be considered by the investor.

The major drawback associated with using net present value is the difficulty in choosing appropriate discount rates. Different investors often have differing minimum required rates of return on new projects. For this reason, it is useful to provide analysis for a range of real discount rates. Table 7 illustrates net present value estimates of both precommercial thinning treatments over a range of control stand densities at age 90 years for the conservative and optimistic diameter projections with real discount rates of 4, 5 and 6%.

<sup>4/</sup> Statistics Canada. National Income Expenditure Accounts. Catalogue 13-201. Quarterly. 1968-1982. 1983 and preliminary 1984 GNE Implicit Price Index obtained by request.

Table 6. Real internal rates of return (%) across various control stand densities at age 90.

## (i) Age class I

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	2.62	1.28	-1.17	-2.59	-3.24	-3.68	-4.00
Optimistic	20.0	17.0	4.51	4.36	4.20	4.01	3.79	3.52	3.19

## (ii) Age class II

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	0.87	0.07	-0.08	-0.83	-1.60	-2.11	-2.49
Optimistic	20.0	17.0	3.09	2.91	2.71	2.50	2.24	1.92	1.53

Two observations can be made from table 7. First, rational investors with real required rates of return of greater than 4% would not consider precommercial thinning in jack pine in either age class. An investor with a 4% required rate of return would accept only the 9-year-old thinning as a worthwhile investment and then only if he was certain that the most optimistic conditions would result.

Second, as illustrated in the IRR analysis, in all cases the 9-year-old thinning appears more economically attractive than the 22-year-old thinning.

## Sensitivity Analysis

In view of the long time periods involved and the

Table 7. Net present value (\$/hectare) estimates for various control stand densities at age 90.

## (i) 4% real discount rate

## Age class I (thinned at 9 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-81	-109	-137	-166	-193	-221	-248
Optimistic	20.0	17.0	60	41	21	1	-19	-39	-58

## Age class II (thinned at 22 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-489	-536	-582	-628	-674	-721	-767
Optimistic	20.0	17.0	-253	-286	-319	-352	-385	-418	-451

(cont'd)



Table 7. Net present value (\$/hectare) estimates for various control stand densities at age 90 (concl.)

(ii) 5% real discount rate

## Age class I (thinned at 9 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-105	-118	-130	-144	-156	-169	-181
Optimistic	20.0	17.0	- 38	- 48	- 57	- 66	- 75	- 75	- 94

## Age class II (thinned at 22 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-523	-547	-571	-596	-620	-644	-668
Optimistic	20.0	17.0	-400	-417	-434	-452	-469	-486	-503

(iii) 6% real discount rate

## Age class I (thinned at 9 years)

	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-113	-120	-126	-132	-138	-145	-151
Optimistic	20.0	17.0	- 85	- 89	- 93	- 98	-102	-106	-110

## Age class II (thinned at 22 years)

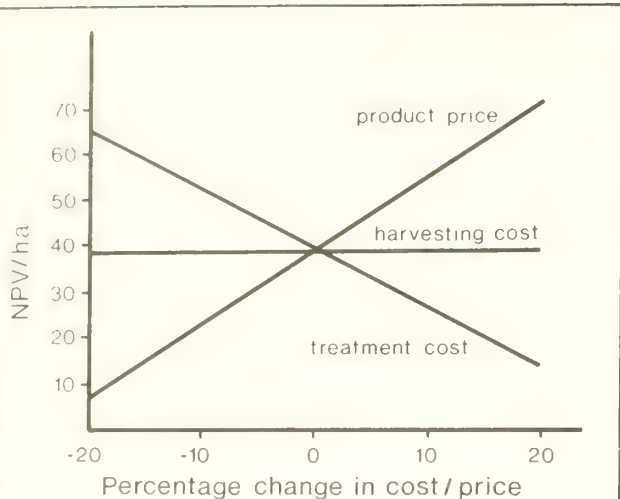
	Thinned stand DBH at age 90 (cm)	Control stand DBH at age 90 (cm)	Control stand density at age 90 (trees/ha)						
			900	950	1000	1050	1100	1150	1200
Conservative	20.0	19.5	-540	-533	-566	-578	-591	-604	-617
Optimistic	20.0	17.0	-476	-485	-494	-503	-512	-521	-530

number of assumptions made, it is necessary to explore the sensitivity of this investment opportunity to changes in costs and prices.

## Age class I (9-year-old thinning)

Figure 3 illustrates the sensitivity of NPV at a 4% discount rate to changes in treatment cost, harvesting cost and revenue for the 9-year-old thinning. The optimistic projection of diameter

increment is used and the control is assumed to thin itself naturally to 950 stems per ha at age 90 years. Price changes have the most pronounced effect on NPV. A 20% real decrease in prices prompts NPV to fall close to \$0 per ha from \$41.00 per ha. A 20% increase in treatment cost would cause NPV to fall to \$16.00 per ha from \$41.00 per ha. Real changes in harvesting costs have only a slight effect on NPV in the 9-year-old thinning.



Assumptions:

- 1) Average diameter of thinned stand is 20.0 cm at age 90,
- 2) Average diameter of control stand is 17.0 cm at age 90,
- 3) Density of thinned stand is 920 stems/ha at age 90,
- 4) Density of control stand is 950 stems/ha at age 90,
- 5) The control stand and the thinned stand are both harvested at age 90,
- 6) Real discount rate is 4%.

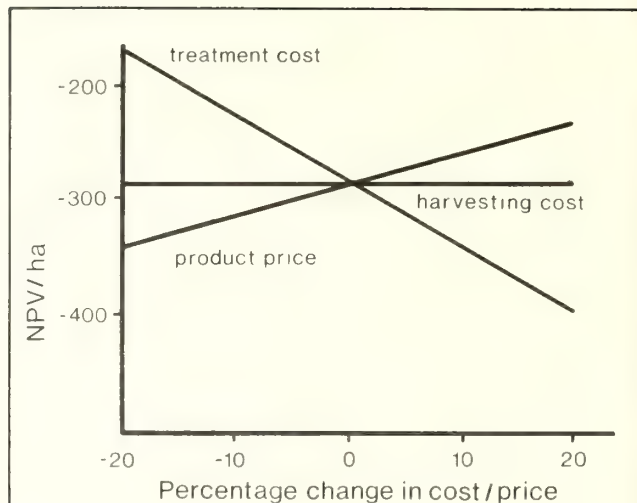
Figure 3.--Sensitivity of NPV in age class I treatment to changes in costs and prices.

Age class II (22-year-old thinning)

Figure 4 illustrates the sensitivity of NPV per ha in the age class II thinning to changes in costs and prices. (The most optimistic projection of the average diameter of the thinned stand over the control stand is assumed, and the control is assumed to have a density of 950 stems per ha at age 90.)

Unlike that of the age class I thinning, the NPV of the age class II thinning is most sensitive to initial treatment cost. In figure 4 it can be seen that if treatment costs increased by 20%, then NPV would be reduced by \$112.00 per ha. A 20% decrease in real prices would reduce NPV by \$56.00 per ha. Again, real changes in harvesting costs have only a negligible effect on NPV per hectare.

If real treatment costs were halved to \$280.00 from \$560.00 per ha, then NPV per



Assumptions:

- 1) Average diameter of thinned stand is 20.0 cm at age 90,
- 2) Average diameter of control stand is 17.0 cm at age 90,
- 3) Density of thinned stand is 920 stems/ha at age 90,
- 4) Density of control stand is 950 stems/ha at age 90,
- 5) The control stand and the thinned stand are both harvested at age 90,
- 6) Real discount rate is 4%.

Figure 4.--Sensitivity of NPV in age class II treatment to changes in costs and prices.

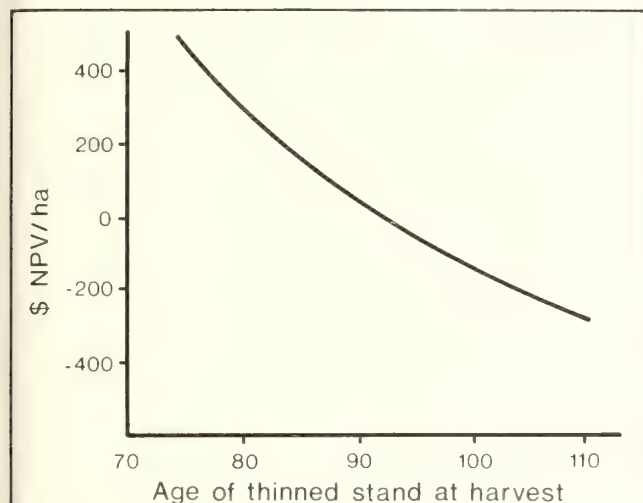
hectare would become positive for the age class II thinning, at a real discount rate of 4%. It is worth noting that a net revenue of \$280.00 per ha produced at time of thinning (i.e., approximately 10 m<sup>3</sup>/ha of pulpwood) would have the same economic impact as reducing the treatment cost by 50%.

Sensitivity to rate of development of the thinned stands

Thus far it has been assumed that the controls and the thinned stands will be harvested at age 90 years. It is necessary, however, to explore the sensitivity of economic returns to changes in the rate of development of the thinned stands.

Figures 5 and 6 illustrate the effect of the timing of the final harvest (i.e., the rate of development of thinned stands) on NPV per ha for

the age class I and age class II thinnings, respectively. It is assumed that at harvest the controls will have an average breast height diameter of 17.0 cm and a density of 950 stems per ha in comparison with 20.0 cm and 920 stems per ha for the thinned stands. A real discount rate of 4% is used.



#### Assumptions:

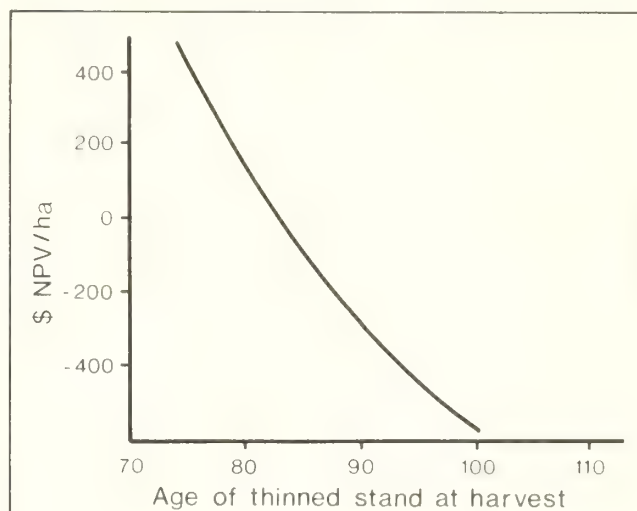
- 1) Average diameter of thinned stand at time of harvest is 20.0 cm,
- 2) Average diameter of control stand at time of harvest is 17.0 cm,
- 3) Density of thinned stand at time of harvest is 920 stems/ha,
- 4) Density of control stand at time of harvest is 950 stems/ha,
- 5) The control stand is harvested at age 90,
- 6) Real discount rate is 4%.

Figure 5.--Sensitivity of NPV in age class I treatment to changes in rate of development.

In figure 5 it can be seen that a reduction in the time required until the age class I thinned stand reaches 20.0 cm has a dramatic effect on NPV per ha. If we assume optimistically that the thinned stand was harvested at age 80 years and the poorer quality control stand was harvested at age 90 years, the NPV of the pre-commercial thinning would increase from \$41.00 per ha to \$300.00 per ha.

The effect is even more dramatic in the age class II treatment. Figure 6 illustrates that a reduction in the age of harvest of the thinned stand from 90 to 80 years, just 10 years before the control is harvested, increases NPV from a loss of \$286.00 to a profit of \$147.00 per ha.

Clearly a reduction in the investment period and the production of a superior stand makes the precommercial thinning treatment a far more promising investment opportunity.



#### Assumptions:

- 1) Average diameter of thinned stand at time of harvest is 20.0 cm,
- 2) Average diameter of control stand at time of harvest is 17.0 cm,
- 3) Density of thinned stand at time of harvest is 920 stems/ha,
- 4) Density of control stand at time of harvest is 950 stems/ha,
- 5) The control stand is harvested at age 90,
- 6) Real discount rate is 4%.

Figure 6.--Sensitivity of NPV in age class II treatment to changes in rate of development.

#### CONCLUSIONS

Average stem diameters responded favorably to the precommercial thinning treatment in both the age class I (thinned at 9 years of age) and the age class II (thinned at 2 years of age) thinnings. Data gathered from the case study to date, however, indicate that the magnitude of diameter increment in the thinned stands in comparison with that in the controls is not sufficient to provide economically attractive returns. Further measurements are required to predict the development of both the thinned and the control stands more accurately. Analysis indicates that the age class I treatment will outperform the age class II treatment. This is due primarily to the high cost of treatment in the age class II study. The present value of



the age class I treatment is sensitive to changes in both product price and initial treatment cost. The present value of the age class II treatment is most sensitive to changes in initial treatment cost. Neither thinning is sensitive to changes in harvesting costs because of the predicted low diameters of both the controls and the thinned stands at the time of harvest. If subsequent measurements indicate that the controls are stagnating or that the thinned stands are outperforming the controls to such an extent that they will be ready for harvest before the controls, then the investment will become far more attractive.

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## A SIMULATION MODEL FOR THE ECONOMIC EVALUATION OF FOREST REGENERATION SYSTEMS

Bijan Payandeh

**Abstract:** This paper briefly discusses the main problems associated with evaluating long-term forestry investments involving risk and uncertainty. A computer model "FIDME" developed to evaluate such investments is then described. Input estimates for the model may be expressed by either point or subjective probability estimates. Simulated results will provide the probability that one investment might differ from others. Therefore, the forest manager will be able to choose, with a known degree of confidence, between investment alternatives. Three examples and model sensitivity are discussed.

### INTRODUCTION

Forest renewal is the most important problem facing forest managers in Canada. Because of the Canadian wood supply situation federal and provincial agencies and the forest industry are to invest increasingly large sums of money annually in forest renewal. Owing to the long-term nature of such investments, they are subject to risk and uncertainty.

In statistical decision theory, a distinction is made between risk and uncertainty. Risk situations are defined as those in which the probabilities of the outcomes are known or can be estimated. Uncertain situations are defined as those in which probabilities cannot be determined for the outcomes. No such distinction between risk and uncertainty will be made here. Generally, the greater the dispersion of the cash flow estimates, the greater the risk. What will the average price of a  $m^3$  of black spruce pulpwood be

in 50 years? Most managers would truthfully say "I don't know". However, investment decisions must be made today on the basis of uncertain future costs and returns. Even though the future stumpage price is unknown, it may be possible to specify a distribution of future prices. Such estimates are of course subjective. They are based on a knowledge of past trends augmented by intuitive feelings about the future.

There are several methods to adjust for risk in long-term investments. The most common method is to use a risk adjusted discount rate defined as  $r = i + p$ , where  $r$  is the risk-free rate and  $p$  is a premium for risk. This approach is based on the premise that risky cash flows are worth less today than certain cash flows and must therefore be discounted at a higher rate. There are two problems associated with the use of the risk-adjusted discount rate. First, it assumes risk is compounding over time. Second, there is no real basis for choosing the appropriate adjustment factor.

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An accepted method of adjusting for uncertainty is the use of certainty-equivalent coefficients. A certainty-equivalent coefficient transforms an



uncertain cash flow into an equivalent certain amount. A certainty-equivalent coefficient for period  $t$  is defined as  $\alpha_t$ , where  $0 \leq \alpha_t \leq 1$ . A certainty-equivalent coefficient of 1 implies that the cash flow is risk-free. A certainty-equivalent coefficient of 0 implies the cash flow is so risky that it has no value. The main problem with this method is, of course, how to assign specific values to the coefficients.

Another way to cope with risk and uncertainty involves the use of subjective probability distributions. This method directly recognizes that the basic cause of risk is variability in the expected future cash flows. Subjective probability estimates may be used not only to account for risk and uncertainty, but they may also be used to quantify an expert's opinion augmented by intuitive feelings about the future outcomes. Several probability distribution functions such as Normal, Gamma, Beta and Weibull have been used for this purpose (cf. Schwitzer 1968, Payandeh and Tucker 1975, Payandeh and Field 1978).

Because of the long-term nature of the forest renewal investments and the risk and uncertainty associated with them, it is essential that they are chosen from the most promising alternatives possible. To evaluate and screen investment alternatives with relative ease and greater precision, forest managers need a technique that enables them to not only predict the rates of return but also indicates the likelihood of their being achieved. This paper briefly describes a computer simulation model developed for comparing the relative economic desirability of various forestry investments subject to risk and uncertainty--particularly those related to forestry renewal activities.

#### BRIEF DESCRIPTION OF THE MODEL

The model is named "FIDME", an acronym for "Forestry Investment Decisions Made Easy". It is an extension of the earlier model "REGEN" (Payandeh and Field 1978). FIDME is basically a very flexible "economic evaluator" or "cash flow analyzer" for comparing long-term forest renewal investment alternatives. Any set of forest regeneration systems and various silvicultural treatments and management actions associated with them may be compared as long as the differences between such regeneration systems can be expressed in terms of differences in costs, probability of success, stocking level, rotation age, expected yield, and future prices, etc. The model contains no assumptions<sup>1/</sup> regarding the stand dynamics and growth as it deals with economic analysis only. However, the input estimates may implicitly reflect the overall assumptions made by the user regarding the interaction of econom-

ic, physical and biological factors affecting various regeneration systems.

The model is an easy-to-use simulation model that will assist forest managers, policy makers and administrators in making rational economic decisions on various forest renewal investment alternatives. For example, it may be used to compare up to four forest renewal systems based on any one of the four economic criteria of:<sup>2/</sup> 1) cost effectiveness, 2) benefit-cost ratio, 3) present net worth and 4) internal rate of return (cf. Lundgren 1973, Payandeh 1977, and Foster and Brooks 1983).

Each forest renewal system or investment alternative may consist of one or more of the following types of costs and returns:

#### I. Initial costs:

- a) land value, i.e., purchase price or market value of land/unit area
- b) preparation costs, e.g., site preparation, access road construction, etc.
- c) establishment costs, e.g., cost of planting, cost of seeding, etc.

#### II. Annual costs, e.g., property tax, road maintenance, forest protection and rent, etc.

#### III. Periodic costs, e.g., cost of fertilization, thinning, spraying, etc.

#### IV. Final costs, e.g., harvesting and/or transportation costs (total cost of wood delivered to the mill).

#### V. Terminal cost, e.g., legal fees and/or other cost associated with the sale of the land, etc.

- 2/ Definition of these criteria may be found in most forest management/economics texts. 1) Cost-effectiveness is based on future cost/unit of volume (output). It does not require future price estimation and does not account for the difference in the quality of the products. A forest renewal with the lowest future cost/unit of volume would be the most economical one on this basis. 2) Benefit-cost ratio is the ratio of the sum of discounted returns to the sum of discounted costs. The alternative with the highest benefit-cost ratio would be the most economical one. 3) Present net worth is the difference between the sum of discounted returns and discounted costs. The alternative with the largest present net worth would be the most economical one. Benefit-cost ratio and present net worth are closely related and both require an assumed discount rate and estimation of future prices. 4) Internal rate of return is a discount rate at which the sum of discounted returns and costs are equal or the present net worth is zero. This criterion does not require an assumed discount rate, but it requires estimates of future prices.

1/ The only assumption made in the model regarding the cost of stand establishment is that: an area or a site may be regenerated up to a maximum of three times per site preparation and that it might be site prepared up to a maximum of three times to produce a successful regeneration.

The investment returns might be one or more of the following types:

- I. Annual returns, e.g., users fees for hunting or fishing, etc.
- II. Periodic returns, e.g., proceeds from commercial thinning, etc.
- III. Final return, e.g., revenue from final harvest at rotation age.
- IV. Terminal return, i.e., future market value of the land/unit area.
- V. Final product price, future price/unit for the final products.

In the model up to four products, e.g., pulpwood, pole timber, saw timber and veneer, and four prices may be specified. The input for the model may be either in the form of point estimate (when the input estimate is known or may be determined free of error) or subjective or judgmental probability estimates (cf. Englehard and Anderson 1983, Yared 1983).

Like its predecessor "FIDME" uses mainly subjective or judgmental estimates provided by the forest manager based on his experience with a given forest renewal system. Such estimates are used in the model to generate appropriate probability distributions via the Weibull function. Each distribution so generated will represent the frequency distribution of a given cost, expected stocking level, future yield or product prices for any reforestation system that the forest manager wishes to specify.

The model is designed such that it simulates all forestry investments in question in a parallel manner. For example, in the case of comparing, say three regeneration systems, the area(s) or site(s) characterized by the input variables are reforested by the regeneration systems enough times to produce a desired number, e.g., 300, of successful reforestations or "successes". All costs and returns associated with a successfully regenerated stand (including the cost of regeneration failures, if any) are properly analyzed, i.e., compounded or discounted depending on criteria used.<sup>3/</sup> Finally a frequency distribution of the final results, expressed by any of the four economic criteria mentioned earlier, for each reforestation system is constructed, and from this the results can be obtained for a desired probability level.

Because various investment alternatives are simulated in a parallel manner to produce an equal number of "successes" and since the results are calculated on per unit output or area, the results of different operations are directly comparable. That is, all differences in costs (initial, annual, periodic and final costs), probability of success, stocking level, rotation age, expected returns (annual, periodic, final and terminal returns), and future product prices, etc. are accounted for.

FIDME is written in structured FORTRAN 77 and may be run interactively or in a batch mode. Input for the model can be entered from the terminal or may be read from an input file. The output similarly may be directed to the terminal or the line printer.

#### EXAMPLES OF MODEL APPLICATION

The application of the model is demonstrated here by describing three examples in some details. Although attempts were made to use current cost estimates where possible, the main objective of the examples is to show the model capability and flexibility and not to recommend one regeneration system over another one. The input estimates for the examples were mainly obtained from the recent literature (e.g., Anon. 1974, Mullin and Howard 1973, Waldron 1974, Olson et al. 1978, Bradley and Lothner 1982) and from several forest managers from the Ontario Ministry of Natural Resources.<sup>4/</sup>

In the first example the cost-effectiveness of pulpwood production from planting and seeding jack pine (*Pinus banksiana* Lamb.) are compared. This example may apply to a large area of clear cut on crown land in Ontario most suitable for growing jack pine. The main question facing the forest manager in this case, would be to seed or to plant the area. The forest manager knows from experience that the cost of planting such an area is much greater than that of seeding. On the other hand the chance of success in regeneration with planting is considerably better than seeding. He also knows that jack pine seeded stands

<sup>3/</sup> For example, present net worth is calculated as:

$$PNW = \frac{V_1(1+i)^1}{(1+r)^1} + \dots + \frac{V_j(1+i)^j}{(1+r)^j} + \dots + \frac{V_n(1+i)^n}{(1+r)^n} \quad (1)$$

where: PNW = present net worth \$/unit area.  
 $V_j$  = the cost or return in the  $j^{th}$  year.  
 $i$  = average inflation rate/year.  
 $r$  = average interest rate/year.  
 $n$  = rotation age.

Benefit-cost ratio is calculated from the above formula as the ratio of the sum of discounted returns over the discounted costs.

Internal rate of return is calculated by iterative solution of equation (1) above to find a value for  $r$  which equates PNW to zero.

For cost-effectiveness criteria the sum of future costs at rotation age are calculated from which future costs/unit volume is derived.

<sup>4/</sup> Calvert, R. 1984. Ontario Ministry of Natural Resources, Timmins, Regional Office. Personal communication.



require at least one precommercial thinning at about 15 years of age. It is also assumed that the rotation age for seeded stands would be up to 10 years longer than planted stands or equivalently, the yield from seeded stands would be less than planted stands for the same rotation age.

Input estimates for the first example are summarized in Table 1. This example does not include input estimates for annual and liquidation costs and annual, periodic and terminal returns since such costs and returns do not usually apply to the crown land. In the case of planting jack pine bare-root stock are assumed to be planted at a rate of about 1900 trees/ha.

Table 1 provides subjective estimates for the cost of light mechanical site preparation required for planting jack pine as: a) low estimate = \$110.00, b) high estimate \$140.00, c) the probability that the cost of site preparation might be lower than the low estimate = 0.10, d) the probability that the cost of site preparation for planting jack pine might be lower than the high estimate = 0.95 and e) the minimum cost of light mechanical site preparation = \$100/ha. Similarly, the five subjective estimates for the cost of heavy mechanical site preparation required for seeding jack pine were: \$250.00, \$320.00, 0.10, 0.95 and \$230.00/ha.

Table 1. Input estimates of Model "FIDME" for comparing the cost-effectiveness of planting and seeding jack pine

Input estimate	Regen. method	Point estimate	Subjective estimates				
			Low	High	Prob. low	Prob. high	Minimum
Site preparation <sup>1/</sup>	plant.)	--	110	140	0.10	0.95	100
	seed.)	--	250	320	0.10	0.95	230
Establishment <sup>2/</sup>	plant.)	--	250	350	0.05	0.95	225
	seed.)	--	30	60	0.10	0.90	20
Stocking standard	plant.)	--	0.45	0.65	--	--	--
	seed.)	--	0.45	0.65	--	--	--
Expected stocking	plant.)	--	0.40	0.95	0.10	0.90	0.35
	seed.)	--	0.20	0.95	0.10	0.80	0.00
Periodic cost <sup>3/</sup>	plant.)	--	--	--	--	--	--
	seed.)	--	75	300	0.05	0.80	50
Product #1 yield m <sup>3</sup> /ha	plant.)	--	200	300	0.10	0.95	150
	seed.)	--	150	250	0.10	0.95	120
Product #1 price \$1/m <sup>3</sup> <sup>3/</sup>	plant.)	--	1.5	2.00	0.10	0.90	1.00
	seed.)	--	1.5	2.00	0.10	0.90	1.00
Economic criteria cost-effectiveness							
Rotation age			70 years				
Interest rate			10%				
Inflation rate			5%				
No. of iteration			300				
Random number generator starter (seed)			13345				

<sup>1/</sup> A maximum is required for the number of scarifications/site beyond which the site is considered abandoned due to repeated unsuccessful regeneration. Also a maximum is required for the number of regeneration operations/site preparation beyond which the area will not be rescarified. Such maximum for the above examples were 2 and 3 for both regeneration systems.

<sup>2/</sup> For periodic costs and returns a start, an interval and an end year are required.

<sup>3/</sup> The period for which future prices are estimated, e.g., 5, 10 or 20 years, is required beyond which future prices are projected based on the inflation rate.

Subjective estimates for the cost of planting jack pine bare-root stock were: a) low estimate of \$250.00, b) high estimate of \$350.00, c) the probability that cost of planting jack pine may be less than the low estimate = 0.05, d) the probability that planting jack pine may be less than the high estimate = 0.95 and the absolute minimum cost of planting jack pine bare-root stock = \$225.00/ha. Likewise, the subjective estimates for the cost of seeding jack pine were: a) low estimate = \$30.00, b) high estimate = \$60.00, c) the probability that cost of seeding jack pine may be lower than the low estimate = 0.10, d) the probability that cost of seeding jack pine may be less than the high estimate = 0.90 and e) the absolute minimum cost of seeding jack pine = \$20/ha. Stocking standards are specified as interval estimates and are the same for both regeneration systems. In the simulation process if a regeneration system results in stocking level less than .45, it would be considered a failure and the site (or area) would be replanted. When a regeneration method results in a stocking of .65 or better, it would be considered a successful regeneration.

Subjective estimates for the expected stocking levels for planting jack pine are given as: a) low estimate = 0.40, b) high estimate = 0.95, c) the probability of stocking being lower than the low estimate = 0.10, d) the probability that stocking may be lower than the high estimate = 0.90 and the absolute minimum stocking for planting jack pine = 0.35. The five subjective estimates for the expected stocking level for seeding jack pine are: a) low estimate = 0.20, b) high estimate = 0.95, c) the probability that stocking may be less than the low estimate = 0.10, d) the probability that stocking level may be less than the high estimate = 0.80 and e) the absolute minimum expected stocking level from seeding jack pine = 0.00.

Subjective estimate for the cost of precommercial thinning for seeding jack pine is given as periodic cost to occur at age 15 years as: a) low estimate = \$75.00, b) high estimate = \$300.00, c) the probability that cost of thinning may be lower than the low estimate = 0.05, d) the probability that the cost of thinning may be lower than the high estimate = 0.80 and e) the absolute minimum for the cost of thinning = \$50.00/ha.

In the first two examples, it is assumed that the final yield would be harvested as a single product in the form of pulpwood. Subjective estimates for the final yield for planting jack pine were: a) low estimate = 200 m<sup>3</sup>/ha, high estimate = 300 m<sup>3</sup>/ha, c) the probability that the yield of pulpwood/ha for jack pine plantation might be less than the low estimate = 0.10, d) the probability that the yield/ha might be less than the high estimate = 0.95 and e) the absolute minimum yield of pulpwood = 150 m<sup>3</sup>/ha. Similarly the estimates of yield/ha at rotation age for the seeded jack pine stand were: a) low estimate = 150 m<sup>3</sup>/ha, b) high estimate = 250 m<sup>3</sup>/ha, c) the probability that yield/ha from seeding jack pine may be less than the low estimate = 0.10, d) the



probability that the yield estimate might be less than the high estimate = 0.95 and e) the absolute minimum yield of pulpwood from seeded jack pine stand = 120 m<sup>3</sup>/ha. Future (i.e., ten years hence for the examples given here) pulpwood prices used were: a) low estimate = \$1.50/m<sup>3</sup>, b) high estimate = \$2.00/m<sup>3</sup>, c) the probability that pulpwood price might be less than the low estimate = 0.10, d) the probability that jack pine pulpwood price might be less than the high estimate = 0.90 and e) the absolute minimum for future pulpwood price = \$1.00/m<sup>3</sup>. Other input estimates for the first example are given at the bottom of Table 1.

In the second example three regeneration systems are compared on the basis of present net worth criteria. This example may also apply to large cutover areas of crown land in Ontario. It is assumed that three sites are involved here, the first one being most suitable for growing jack pine (e.g., sand flat site), the second area being most suitable for growing black spruce (e.g., peatland site), and the third area being most suitable for growing white spruce (e.g., an upland site). It is further assumed that bare-root stock will be planted in the case of jack pine and black spruce which require light mechanical site preparation and containerized tree seedlings will be used in the case of white spruce which requires heavy mechanical site preparation. The main differences in site productivity between the three areas are reflected in the rotation ages used and estimates of final yield for the three regeneration systems being compared.

Input estimates for the second example are summarized in Table 2. It is noted that the input estimates for planting jack pine bare-root stock is identical to that of the first example. Subjective estimates for the cost of site preparation and planting are assumed to be the same for both planting jack pine and black spruce bare-root stock as given in Table 2. Estimates for the cost of site preparation for planting containerized white spruce tree seedlings are given: a) low estimate = \$250.00, b) high estimate = \$320.00, c) the probability that the cost of site preparation may be less than the low estimate = 0.10, d) the probability that the cost of site preparation may be less than the high estimate = 0.95 and e) the absolute minimum cost of site preparation = \$230.00/ha. Similarly, the five subjective estimates for the cost of planting containerized white spruce tree seedlings were: \$150.00, \$230.00, 0.10, 0.95 and \$130.00/ha.

Stocking standard for the three regeneration systems specified by interval estimates were the same as in the first example as: low = 0.45 and high = 0.65. The five subjective estimates for the expected stocking for the three regeneration systems were: 0.40, 0.95, 0.10, 0.90 and 0.35 for planting jack pine, 0.35, 0.90, 0.10, 0.95, and 0.30 for planting black spruce and 0.45, 0.95, 0.05, 0.95 and 0.40 for planting white spruce containerized seedlings, respectively. Subjective estimates for the final yield for the three regeneration systems were: 200 m<sup>3</sup>, 300 m<sup>3</sup>,

Table 2. Input estimates for Model "FIDME" for economic comparison of three regeneration systems of planting jack pine and black spruce bare-root stock and white spruce containerized seedlings on three different sites

Input estimate	Regen. method	Point estimate	Subjective estimates				
			Low	High	Prob. low	Prob. high	Minimum
Site preparation \$/ha <sup>1</sup> /	Pj BR)	--	110	140	0.10	0.95	100
	Sb BR)	--	110	140	0.10	0.95	100
	Sw Con)	--	250	320	0.10	0.95	230
Establishment \$/ha <sup>1</sup> /	Pj BR)	--	250	350	0.10	0.95	225
	Sb BR)	--	250	350	0.10	0.95	225
	Sw Con)	--	150	230	0.10	0.95	130
Stocking standard	Pj BR)	--	0.45	0.65	--	--	--
	Sb BR)	--	0.45	0.65	--	--	--
	Sw Con)	--	0.45	0.65	--	--	--
Expected stocking	Pj BR)	--	0.40	0.95	0.10	0.90	0.35
	Sb BR)	--	0.35	0.90	0.10	0.95	0.30
	Sw Con)	--	0.45	0.95	0.05	0.95	0.40
Product #1 yield m <sup>3</sup> /ha	Pj BR)	--	200	300	0.10	0.95	150
	Sb BR)	--	180	230	0.10	0.95	150
	Sw Con)	--	280	350	0.10	0.90	250
Product #1 price \$/m <sup>32</sup> /	Pj BR)	--	1.50	2.00	0.10	0.90	1.00
	Sb BR)	--	1.50	2.00	0.10	0.90	1.00
	Sw Con)	--	1.50	2.00	0.10	0.90	1.00
Rotation age years	Pj BR)	70	--	--	--	--	--
	Sb BR)	90	--	--	--	--	--
	Sw Con)	80	--	--	--	--	--
Interest rate		12%					
Inflation rate		5%					
No. of iteration		300					
Random No. seed		135					

1/ Same as in 1/ Table 1.

2/ Same as in 3/ Table 1.

0.10, 0.95 and 150 m<sup>3</sup>/ha for planting jack pine, 180 m<sup>3</sup>, 230 m<sup>3</sup>, 0.10, 0.95, and 150 m<sup>3</sup>/ha for planting black spruce, and 280 m<sup>3</sup>, 350 m<sup>3</sup>, 0.10, 0.90, and 250 m<sup>3</sup>/ha for planting containerized white spruce seedlings. Future (i.e., ten years hence for these examples) pulpwood prices were the same for the three regeneration systems as given before (see Tables 1 and 2).

Input estimates for the third example are summarized in Table 3. This example compares the relative economic desirability of three investment alternatives of growing timber for pulpwood and/or saw log production with that of Christmas tree production on three different areas (sites). This example may apply to privately owned forest lands and is presented here mainly to demonstrate the flexibility of the model application. The objective of such an economic comparison might be to rank or prioritize the areas for investment by the land owner based on the expected rate of return from each alternative investment.

The initial cost (i.e., the market value of the land \$/ha) for the three sites for planting jack pine, black spruce and Scots pine (*Pinus sylvestris* L.) are assumed to be \$100.00, \$25.00 and \$500.00/ha, respectively. Since the present value of land is either known or is subject to minor variability, point estimates were used in this case. The difference between the initial cost for the three sites presumably reflects the difference in value of the land due to differences in site quality, location, accessibility

and other factors affecting the market value of forest lands. Subjective estimates for the cost of site preparation and regeneration establishment for both planting jack pine and black spruce are identical to the previous example. In the case of Scots pine plantation, however, it is assumed to require intensive site preparation similar to that of containerized planting as given in Table 2. The cost of planting for Scots pine is assumed to be the same as that of jack pine and black spruce (see Table 3). Stocking standard for all three regeneration systems are assumed to be the same as in the previous examples. The expected stocking for both planting jack pine and black spruce were also assumed to be the same as those given in the previous example. The five subjective estimates for the expected stocking for Scots pine were: a) low estimate = 0.80, b) high estimate 0.95, c) the probability that the expected stocking might be lower than the low estimate = 0.10, d) the probability that the expected stocking might be lower than the high estimate = 0.95, and e) the absolute minimum for expected stocking = 0.50.

The annual cost/ha, i.e., property tax, etc., were assumed to be \$4.00, \$1.00 and \$20.00/ha/year for the three sites, respectively. In the case of jack pine plantation it was assumed that it will be thinned twice at the ages of 15 and 35 years, the latter being a commercial thinning. The subjective estimate for the cost of both thinnings were assumed to be the same as those given for the first example. No periodic costs were assumed in the case of planting black spruce as indicated in Table 3. The costs of tending the Scots pine plantation were expressed in the form of two periodic costs: one for herbicide spraying to reduce competing vegetation and the other for pruning and shaping individual trees. It was assumed that herbicide application will begin in the second year and will be repeated every other year until age eight years. Subjective estimates for the cost of spraying (Olson et al. 1979) were as: a) low estimate = \$35.00, b) high estimate = \$60.00, c) the probability that the cost of spraying will be less than the low estimate = 0.10, d) the probability that the cost of spraying will be less than the high estimate = 0.90 and e) the absolute minimum for the cost of spraying = \$30.00/ha. It was also assumed that the pruning operation will begin at the first year and it will be carried on every year until year 9, one year before harvesting. Table 3 gives the five subjective estimates for the cost of pruning as: \$120.00, \$150.00, 0.10, 0.90 and \$100/ha.

The next input estimate given in Table 3 is the liquidation cost, e.g., commission and legal fees for the sale of the land for the Scots pine plantation site as \$50.00/ha. It is assumed that the Christmas tree site will be sold following the second rotation, i.e., after 20 years, at \$700.00/ha. Annual return, e.g., users fee for hunting, fishing, picnicking, etc., for the jack pine site is assumed to be \$4.00/ha. It is assumed that the commercial thinning applied to the jack pine stand at the age of 35 will result in a periodic return of: a) low estimate =

Table 3. Input estimates for Model "FIDME" for economic comparison of three forestry investment alternatives of planting jack pine and black spruce bare-root stock for pulpwood and/or saw log production and planting Scots pine for Christmas tree production on three privately owned sites

Input estimate	Invest. method	Point estimate	Subjective estimates				
			Low	High	Prob. low	Prob. high	Minimum
Initial cost \$/ha	Pj BR)	100	--	--	--	--	--
	Sb BR)	25	--	--	--	--	--
	Ps Ch)	500	--	--	--	--	--
Site preparation \$/ha <sup>1/</sup>	Pj BR)	--	110	140	0.10	0.95	100
	Sb BR)	--	110	140	0.10	0.95	100
	Ps Ch)	--	250	320	0.10	0.95	230
Establishment \$/ha <sup>1/</sup>	Pj BR)	--	250	350	0.05	0.95	225
	Sb BR)	--	250	350	0.05	0.95	225
	Ps Ch)	--	250	350	0.05	0.95	225
Stocking standard	Pj BR)	--	0.45	0.65	--	--	--
	Sb BR)	--	0.45	0.65	--	--	--
	Ps Ch)	--	0.45	0.65	--	--	--
Expected stocking	Pj BR)	--	0.40	0.95	0.10	0.90	0.35
	Sb BR)	--	0.35	0.90	0.10	0.95	0.30
	Ps Ch)	--	0.80	0.95	0.10	0.95	0.50
Annual cost \$/ha	Pj BR)	4	--	--	--	--	--
	Sb BR)	1	--	--	--	--	--
	Ps Ch)	20	--	--	--	--	--
Periodic cost #1 \$/ha <sup>2/</sup>	Pj BR)	--	75	300	0.05	0.80	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	35	60	0.10	0.90	30
Periodic cost #2 \$/ha <sup>2/</sup>	Pj BR)	--	75	300	0.05	0.80	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	120	150	0.10	0.90	100
Liquidation cost \$/ha	Pj BR)	--	--	--	--	--	--
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	50	--	--	--	--	--
Annual return \$/ha <sup>3/</sup>	Pj BR)	4	--	--	--	--	--
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Periodic return \$/ha <sup>2/</sup>	Pj BR)	--	60	100	0.20	0.80	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Terminal return \$/ha	Pj BR)	--	--	--	--	--	--
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	700	--	--	--	--	--
Product #1 m <sup>3</sup> /ha (trees/ha)	Pj BR)	--	150	200	0.10	0.95	100
	Sb BR)	--	180	230	0.10	0.95	150
	Ps Ch)	--	800	950	0.10	0.90	700
Product #1 price \$/unit <sup>4/</sup>	Pj BR)	--	1.50	2.00	0.10	0.90	1.00
	Sb BR)	--	1.50	2.00	0.10	0.90	1.00
	Ps Ch)	--	3	5	0.10	0.90	2.50
Product #2 m <sup>3</sup> /ha	Pj BR)	--	75	100	0.10	0.95	50
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Product #2 price \$/unit <sup>4/</sup>	Pj BR)	--	10.00	15.00	0.10	0.90	5.00
	Sb BR)	--	--	--	--	--	--
	Ps Ch)	--	--	--	--	--	--
Rotation age (years)	Pj BR)	70	--	--	--	--	--
	Sb BR)	70	--	--	--	--	--
	Ps Ch)	10	(analysis carried out for two rotations)				
Interest rate		10%					
Inflation rate		5%					
No. of iteration		300					
Random No. seed		1235					

1/ Same as in 1/ Table 1.

2/ In the case of annual costs and returns, a start and an end year is required.

3/ Same as 2/ in Table 1.

4/ Same as 3/ in Table 1.



\$60.00, b) high estimate = \$100.00, c) the probability that the periodic return will be less than the low estimate = 0.20, d) the probability that the return from commercial thinning will be less than the high estimate = 0.80 and e) the absolute minimum from periodic return = \$50.00/ha.

In the case of jack pine plantation, it is also assumed that the final yield will be in the form of two products of pulpwood and saw log. The five subjective estimates for pulpwood production were: 150, 200, 0.10, 0.95 and 100 m<sup>3</sup>/ha and those for saw log production were: 75, 100, 0.10, 0.95 and 50 m<sup>3</sup>/ha. In the case of black spruce plantation, the final yield is assumed to be used as pulpwood only and the estimates were the same as in the previous example. The final product from the Scots pine planation is expressed as the number of Christmas trees/ha harvested as: a) low estimate = 800, b) high estimate = 950, c) the probability that the number of Christmas trees will be less than the low estimate = 0.10, d) the probability that the number of trees will be less than the high estimate = 0.90 and e) the absolute minimum estimate = 700 Christmas trees/ha. Future (i.e., ten years hence for this example) pulpwood prices used for the jack pine and black spruce were the same as in the previous examples. The subjective estimates for the future price of Scots pine Christmas trees (on the stump) were: a) low estimate = \$3.00, b) high estimate = \$5.00, c) the probability that future price will be less than the low estimate = 0.10, d) the probability that the future price will be less than the high estimate = 0.90 and e) the absolute minimum = \$2.5/tree. Finally, the five subjective estimates for future price of saw log jack pine were assumed to be: \$10.00, \$15.00, 0.10, 0.90 and \$5.00/m<sup>3</sup>. Other input estimates for the third example are given at the bottom of Table 3.

## RESULTS (OUTPUT) AND INTERPRETATION

As mentioned earlier the sole purpose of the examples used above and the results described here is to demonstrate the model application and its flexibility and not to recommend a specific regeneration system. Some of the assumptions made may only apply to hypothetical situations, nevertheless the examples should serve to demonstrate the model capabilities and applications.

Results of the first example are summarized in Table 4. The first column of Tables 4-6 labelled "Probability of exceeding" applies to the remaining columns in these tables. The second row (or line) of Table 4 indicates, for example, that there is a 10% chance that the future cost per m<sup>3</sup> of pulpwood will exceed \$84.04 for planting jack pine and \$76.06 for seeding jack pine. Conversely, there is a 90% chance that the future cost per m<sup>3</sup> of pulpwood would be equal to or less than these figures for planting and seeding jack pine. Future cost difference between planting and seeding jack pine is given in column 4 of there is a 10% chance that the future cost of a m<sup>3</sup> of pulpwood from a jack pine seeded stand will be less than that of a jack pine planation by

\$7.98. Line 3 of Table 4 indicates that there is a 20% chance that the future cost of pulpwood per m<sup>3</sup> will exceed \$65.94 from jack pine plantations and \$67.99 from jack pine seeded stands. Conversely, Table 4 indicates that there is an 80% chance that the future cost per m<sup>3</sup> will be between \$27.50 and \$65.94 for pulpwood from jack pine plantation and between \$29.32 and \$67.99 for pulpwood from seeded jack pine stands. Column 4 of table 4 also indicates that there is an 80% chance that future cost per m<sup>3</sup> of pulpwood from planting jack pine will be less than that from seeded stands by about \$1.82 or more.

As mentioned earlier, the first example should demonstrate the application of the model in fairly simple situations where two or more regeneration systems are to be compared for a given area (or site) and for the same rotation age. In the above example, the main differences between seeding and planting jack pine were expressed in terms of differences in the cost of site preparation, the cost of stand establishment, expected stocking, thinning requirements and the difference in the final yield. Based on the input estimates used for this example, it may be stated that there is only less than a 20% chance that seeding jack pine may be a more cost-effective regeneration system than planting jack pine. On the other hand, there is more than 80% chance that planting jack pine would be a more cost-effective regeneration method than seeding jack pine.

Table 4. Output of simulator "FIDME" for comparing the cost-effectiveness of pulpwood production from planting and seeding jack pine for a rotation age of 70 years, an interest rate of 10% and an inflation rate of 5%

Probability of exceeding	Future cost \$/m <sup>3</sup>		Future cost difference \$/m <sup>3</sup>
	Planting jack pine	Seeding jack pine	Planting - seeding jack pine
0.00	236.47	173.39	63.08
0.10	84.04	76.06	7.98
0.20	65.94	67.99	-2.05
0.30	55.17	63.53	-8.36
0.40	49.26	60.38	-11.12
0.50	45.75	56.98	-11.23
0.60	43.67	53.17	-9.50
0.70	41.07	49.86	-8.79
0.80	38.57	46.60	-8.03
0.90	35.92	42.82	-6.91
1.00	27.50	29.32	-1.82

Table 5 summarizes the results of example 2 in which three regeneration systems of planting jack pine and black spruce bare-root stock and planting white spruce containerized tree seedlings were compared on the basis of present net worth. As indicated in Table 2 the main differences between the three regeneration systems were expressed in terms of the cost of site preparation, the cost of stand establishment, expected stocking level, final yield and rotation ages. Differences in site productivity of the three areas are expressed mainly in terms of the final yield and rotation age. The results of this



example may be used to rank the three areas for regeneration or prioritize the three investment alternatives.

Table 5 compares the three regeneration systems on the basis of present net worth. Line 2 of Table 5, for example, indicates that there is a 10% chance that present net worth/ha might exceed \$444.29 for planting jack pine, \$270.48 for planting black spruce and \$473.65 for planting white spruce containerized seedlings, respectively. This table also indicates that there is a 50% chance that present net worth/ha will be between \$248.45 and \$727.19 for planting jack pine bare-root stock, and between \$118.47 and \$477.83 for planting black spruce bare-root stock and between \$318.40 and \$664.64 for planting white spruce containerized tree seedlings, respectively. It should be noted that where present net worth is positive, it means that the investment is more attractive than the alternative rate of return by that amount/unit area. When present net worth is negative, it means that the investment is less profitable than the alternative rate of return by that amount/unit area. For the above example results indicate that there is less than 20%, 30% and 10% chance, respectively, that these investments might be less profitable than the alternative rate of return. Based on the input estimates used and assumptions made for the second example, it may be concluded that of the three regeneration systems compared planting white spruce will be the most profitable investment followed by planting jack pine and black spruce.

Results of the third and final example are summarized in Table 6. This table compares the three investment alternatives of planting jack pine for pulpwood and saw log production, planting black spruce for pulpwood production and planting Scots pine for Christmas tree production on the basis of internal rate of return. The main differences between the three forestry investments have been expressed not only in the costs of site preparation, plantation establishment, expected stocking, final yield and rotation age, they have also been expressed in terms of

initial cost, annual, periodic and liquidation costs; and annual, periodic and terminal returns. Other differences have been expressed in terms of the number and types of products, e.g., pulpwood versus pulpwood and saw log and Christmas tree production. Also differences have been expressed in terms of future price of different products from each investment. The results of the model application should provide a basis for ranking of the above three investments for the hypothetical forest landowner.

Table 6 provides the expected rate of return from the three investments at 10% probability interval. Line 2 of this table indicates, for example, that there is a 10% chance that the rate of return from planting jack pine would be between 12% to 13% and that from planting black spruce would be about 11% and that from planting Scots pine for Christmas tree production would be between 20% to 22%. Conversely, it indicates that there is a 90% chance that the internal rate of return from planting jack pine would be between 11% to 12% and that from planting black spruce would be between 8% to 11% and that from planting Scots pine would be between 17% to 19%, respectively. This table also indicates that the internal rate of return for planting Scots pine is 6% to 9% higher than that for growing jack pine and is 9% to 11% higher than that for planting black spruce at most probability levels. Therefore the task of ranking the three investment alternatives become fairly simple. Under the assumptions made and based on the input estimates used for this example, planting Scots pine for Christmas tree production would be the most attractive investment followed by planting jack pine for pulpwood and saw log production and planting black spruce for pulpwood production.

#### MODEL SENSITIVITY

A large number of trial runs were conducted to examine the model sensitivity with regard to changes in various input estimates. The results

Table 5. Output of model "FIDME" for economic comparison of three regeneration systems of: planting jack pine and black spruce bare-root stock and planting of white spruce containerized tree seedlings based on present net worth criteria and an interest rate of 12% and inflation rate of 5%

Probability of exceeding	Present net worth \$/ha		
	Planting jack pine	Planting black spruce	Planting white spruce
0.00	727.19	477.83	664.64
0.10	444.29	270.48	473.65
0.20	377.52	231.25	426.37
0.30	330.28	205.53	388.67
0.40	289.47	152.89	358.54
0.50	248.45	118.47	318.40
0.60	217.96	83.42	282.21
0.70	167.19	25.00	250.79
0.80	109.79	-70.36	207.62
0.90	-11.94	-211.33	164.10
1.00	-1041.37	-935.62	-47.83

Table 6. Output of model "FIDME" for example 3 in comparing the relative economic desirability of three forestry investments, namely, planting jack pine for pulpwood and lumber production, planting black spruce for pulpwood production and planting Scots pine for Christmas tree production on the basis of internal rate of return criteria

Probability of exceeding	Internal rate of return		
	Planting jack pine	Planting black spruce	Planting Scots pine
0.00	0.13	0.11	0.22
0.10	0.12	0.11	0.20
0.20	0.12	0.11	0.20
0.30	0.12	0.10	0.20
0.40	0.12	0.10	0.19
0.50	0.12	0.10	0.19
0.60	0.12	0.10	0.19
0.70	0.12	0.10	0.18
0.80	0.12	0.10	0.18
0.90	0.12	0.09	0.18
1.00	0.11	0.08	0.17

of these trial runs may be summarized as follows:

returns--mainly because of their relative magnitude and timing.

#### SUMMARY

The model described above contains significant improvements and modifications over its predecessor "REGEN". It allows comparison of any kind of long term forestry investments consisting of a few to many types of costs and returns. It is mainly an interactive model which allows the use of either point or subjective estimates for nearly all inputs required. If properly used, the model should provide a valuable aid to forest managers in making rational economic decisions on various silvicultural investments--particularly those related to the forest renewal. With the aid of this model, the forest manager may choose a regeneration system with the best chance of being the most economical regeneration system or, alternatively, he may choose the regeneration system that has the best chance of producing wood at the lowest future cost/unit volume.

Application of subjective probability estimates in this model serves a three prong objective: 1) It serves as a built-in mechanism to adjust for the risk and uncertainty associated with the long-term investments under consideration, 2) It provides a simple method of utilizing limited data augmented by personal experience or feelings about future outcomes of given set of conditions, and 3) It allows incorporation of variability and thus associated probability with the results. It is hoped that forest managers will take full advantage of this model in choosing the most appropriate regeneration systems at this critical time.

The model is written in structured FORTRAN 77. A tape copy of the program listing and input examples may be obtained from the author.

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- 1) The model is very sensitive to estimates of expected stocking levels as compared to the stocking standards for all criteria. For example, if stocking standards are reduced by 10%, say from 65% to 55%, for all regeneration systems, the relative performance of the regeneration system with the lowest expected stocking level shows the most improvement and that with the highest expected stocking level results in the least improvement.
- 2) The model is quite sensitive to estimates of the final yield for all criteria and it is also sensitive to the estimates of future prices, except in the case of the cost-effectiveness criterion. That is, if the estimates of the final yield or product prices for all investment are changed by a constant amount, the regeneration system with the lowest yield or product price will be most affected.
- 3) The model is also quite sensitive to initial cost, i.e., land value, cost of site preparation and stand establishment, for all economic criteria. The timing and relative magnitude of these costs have considerable effect on the relative comparison of investments under consideration. For example, if the initial costs for all regeneration systems being compared are doubled, without affecting the final return and product prices, the regeneration system with the lowest initial cost will be most affected. However, if raising the initial cost by a given amount increases the expected stocking levels or reduces the rotation ages proportionately, the relative economic performance of the regeneration system with the lowest initial cost, or the lowest expected stocking level and/or the longest rotation age will improve the most.
- 4) The model can be fairly sensitive to periodic costs and return but this sensitivity is dependent on their relative magnitude and frequency of occurrence. If periodic costs for fertilization or thinning results in the reduction of rotation age and/or increases the final yield for a regeneration system, it might become the factor most affecting the relative economic performance of such a regeneration system.
- 5) The model is somewhat insensitive to the estimates of annual costs and returns, mainly because of their relative magnitudes as compared to other costs and returns. Annual costs and returns do not usually influence the final yield and product prices.
- 6) Finally, the model is least sensitive to the estimates of terminal costs and

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SIXTH INTERNATIONAL WORKSHOP ON FOREST REGENERATION  
AT HIGH LATITUDES

Minutes of the Business Meeting  
Edmundston, New Brunswick, Canada August 10, 1984

The meeting opened with a discussion concerning the 1985 workshop. Owe Martinson briefed us about the proposed agenda for the workshop. It will include 3 days of travel to northern and western Sweden. An additional day will be devoted to the presentation of papers. The meeting will take place June 16-22. Its theme will be, "Regenerating Forests Close to Timberline".

Proposals for the 1986 meeting were also discussed. It was decided that this meeting will be held at Ft. St. John, British Columbia, Canada. The invitation to come to Canada was offered by Bob McMinn of the Pacific Forest Research Centre of the Canadian Forestry Service. Sven-Eric Appelroth proposed that the meeting in 1987 be held in Finland and Russia. His proposal was accepted and the group authorized him to begin arrangements.

The next item on the agenda dealt with our relationship with IUFRO. There was general agreement that our workshop group needed a more formal structure. It was decided that we should try to have a separate working party within Division I of IUFRO. The following motion was passed unanimously:

The chairman of this group is authorized to initiate discussion with IUFRO officials concerning the possibility of this group becoming an official research working unit of IUFRO.

Jim Cayford agreed to be the contact person with IUFRO at their September meeting. He will advise Dick Herman of IUFRO before that meeting of the group's request. He will act on behalf of the chairman. Sven-Eric Appelroth noted that this will increase the chances of having Soviet participation.

Those attending the meeting agreed to have Dr. Andrew Gordon's paper on black spruce published, if submitted, as part of the 1984 proceedings. Dr. Gordon had to cancel his plans to attend the workshop because of his dissertation defense. After much discussion, it was agreed, if possible, that the name of our group should be the Northern Forest Regeneration Working Group. Several alternatives, including boreal, high latitude and taiga were discussed. The working group's goal would be to: "promote the exchange of experience and research results on forest regeneration practices in the northern forest".

Edmond C. Packee of the Agricultural and Forestry Experiment Station of the University of Alaska, U.S.A. was appointed to serve as chairperson.

Respectfully submitted,

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## THEME AND LOCATION FOR THE 1985 WORKSHOP

Owe Martinsson

This workshop is dealing with problems of forest regeneration on northern latitudes and the southern boundary of interest has been set to the 55:th parallel. The influence from the latitude on the forest vegetation is, however, not the same in one part of the world compared to another.

In central and eastern Canada the 55:th parallel runs through a country with severe climatical conditions for forest production and on the other side of the globe the 55:th parallel doesn't even touch the southern part of Scandinavia. Still there are productive forests in northern Norway north of the 70:th parallel. Sweden has well growing beech forests on latitude N 57°, oak grows as a commercial species on latitude N 60° and on lower altitudes there is a commercial forestry of conifers north of the arctic circle.

The warm current from the gulf of Mexico makes the winters in Scandinavia relatively mild and short and the large continent in the east has a continental influence on the summer climate. Besides the northern latitudes of Scandinavia make this area unique in the world in the combination of an almost continuous day light in the growing season and a relatively warm climate.

There are, however, other limitations of forest production which only to some extent are associated with the latitude.

According to the Swedish Act of Forestry a boundary for special problems of regeneration has been established in the north dividing the country in two parts (Fig 1). The boundary is mainly based upon altitude and excludes 3.8 mill hectares of forest land from commercial forestry due to a too big risk for failure of forest regeneration. Most of these forests are containing high quality timber and are today economically attractive.

The Swedish Forest Service and the Swedish Faculty of Forestry have to an ever increasing extent been involved in the task of forest regeneration under these extraordinary conditions. There are several experiments of site preparation, planting and direct seeding close to or above the timber line. Several provenance trials with native and/or introduced tree species were established more than 30 years ago.

In lower elevation areas on the same latitude are detailed descriptions of forest management, seeding, planting, site preparation, controlled burning since 1908 the result of which can be studied today.

In a world of limited resources the problems of regenerating forests not only at northern latitudes but also in areas of high altitude should be of general interest also in other countries of the north.

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# NORTHERN SWEDEN

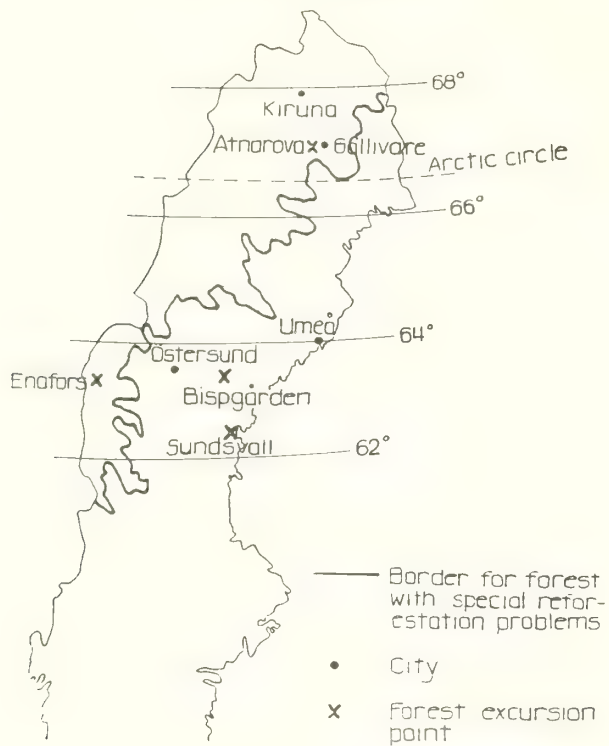


Figure 1. Areas excluded from commercial forestry due to reforestation problems.

Therefore I will suggest that the 1985 meeting of this workshop will take place in northern Sweden under the theme "Regeneration of forests close to the timber line".



LIST OF PARTICIPANTS  
SIXTH INTERNATIONAL WORKSHOP ON FOREST REGENERATION AT HIGH LATITUDES

August 10-11, 1984

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Murray, Mayo, ed. The yield advantages of artificial regeneration at high latitudes. Proceedings, 6th international workshop on forest regeneration: 1984 August 10-11; Edmundston, NB, Canada. Gen. Tech. Rep. PNW-194. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; 1986. 60 p.

The proceedings contains nine papers presented at a workshop on regeneration at high latitudes. The papers reflect work being done in Canada and Scandinavia.

Keywords: Yield, boreal forests, latitudes (-site, regeneration (stand)).



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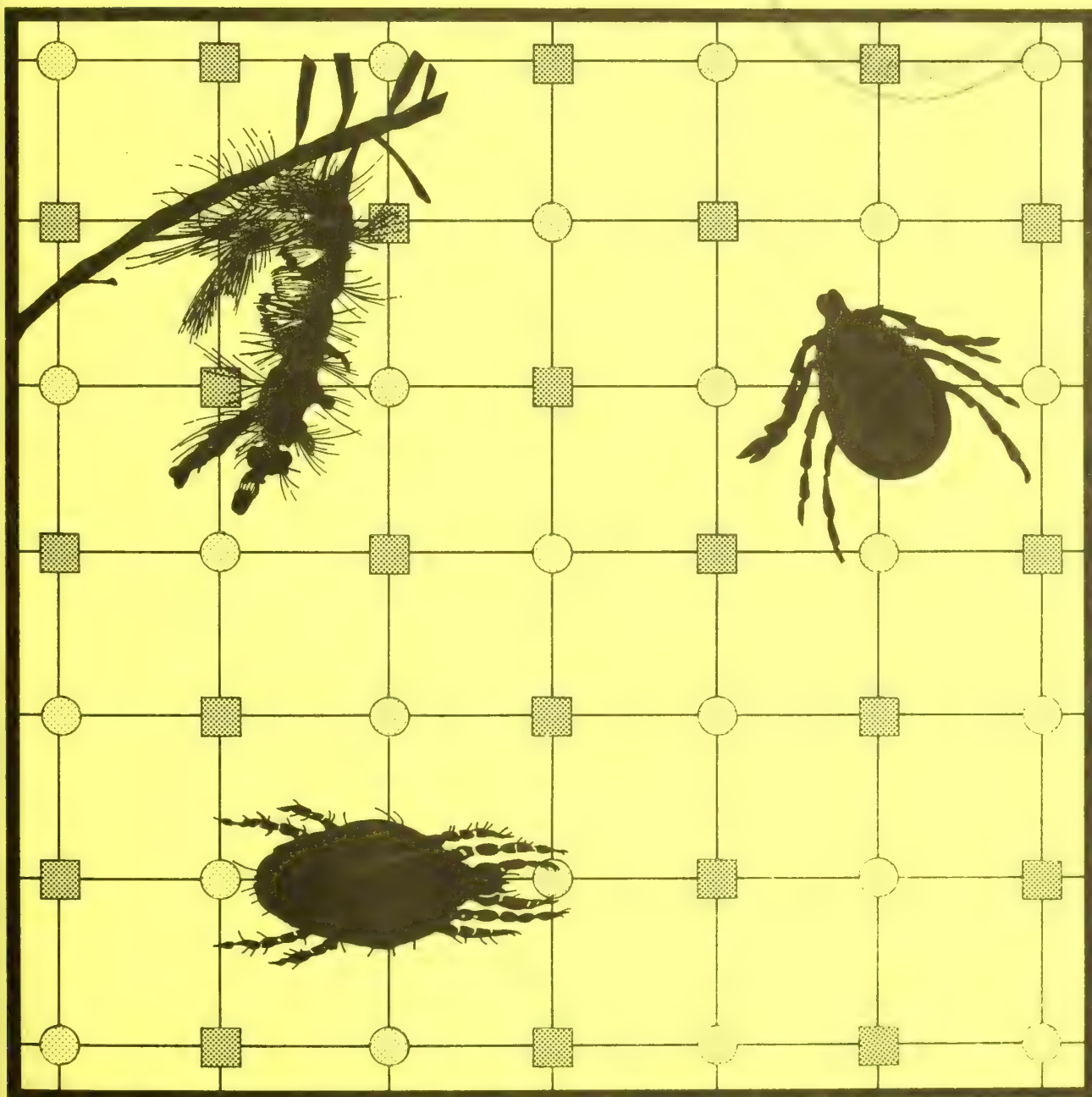


# A Catalog of Viral Diseases of Insects, Mites, and Ticks

Mauro E. Martignoni and Paul J. Iwai

Fourth Edition  
Revised

CLEMSON UNIVERSITY



## **Authors**

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## **Abstract**

**Martignoni, Mauro E.; Iwai, Paul J.** A catalog of viral diseases of insects, mites, and ticks. 4th ed. Gen. Tech. Rep. PNW-195. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986**. 51 p.

This comprehensive catalog of viral diseases of three large groups of arthropods updates the previous surveys of the world's literature published by Hughes in 1957, by Martignoni and Langston in 1960, and by Martignoni and Iwai in 1975. This computer-based catalog lists over 1,100 species of insects, mites, and ticks, each reported to have one or more of 22 viral diseases or disease groups, for a total of about 1,690 host-virus records. The catalog consists of two lists. In the first one, the hosts are listed in taxonomic sequence (order, family, genus, species). Families appear alphabetically within each order, genera alphabetically within each family, and species alphabetically within each genus. In the second, all hosts are listed alphabetically by specific names. The host-virus records are stored on computer tape and disks.

Keywords: Virus (-insecta, mites, virus catalog (computerized), insect damage control (forest), diseases (insect).

## **Previous Editions**

First, 1975, General Technical Report PNW-40

Second, 1977, General Technical Report PNW-40, revised

Third, 1981, Academic Press, New York and London

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<b>6</b>	<b>Acknowledgments</b>
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<b>7</b>	<b>Appendix 1</b>
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<b>29</b>	<b>Alphabetical List of Hosts by Specific Names</b>
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## Introduction

This comprehensive catalog of insects, mites, and ticks reported to have viral diseases is generated from a computer-assisted information system on viral diseases established at the Forestry Sciences Laboratory in 1970 (Martignoni et al. 1973). The present catalog results from our analysis of 4,287 publications (as of this writing). Of these, 733 had been the basis of lists published by Hughes (1957) and by Martignoni and Langston (1960). Those two lists, as well as the current catalog, are not the result of simple title scans; they were generated from a thorough analysis of each article entered in our master file. The methods of input analysis and preparation have been described by Martignoni et al. (1973). The techniques of information storage and retrieval are those of the eight FAMULUS program sub-systems described by Burton et al. (1969). The data base for this catalog is preserved in a master file (on magnetic tape, disks, and paper) at the Forestry Sciences Laboratory, Corvallis. We emphasize that the data base consists only of published host records. Unpublished host records (material stored in virus collections, internal laboratory reports, and personal correspondence) do not appear in the catalog. The catalog lists over 1,100 host species, each reported to have one or more of 22 viral diseases or disease groups, for a total of about 1,690 host-virus records.

Computer programs for the preparation of this catalog were developed in cooperation with the Pacific Northwest Research Station's biometrics service. These programs sort and list species of arthropods, along with their viral diseases, in two separate printouts:

- Orders listed in alphabetical sequence; families listed alphabetically within each order; genera listed alphabetically within each family; species and subspecies listed alphabetically within each genus (see p. 7).
- Specific names listed alphabetically; if a species has one or more subspecies, these are also listed alphabetically (see p. 27). This list disregards arrangement by higher taxonomic categories (genus, family, and order), and it serves as a general host index by specific names.

The key to the disease codes, on the last page of this catalog, can be unfolded to the right side of the pamphlet for convenience.

Our catalog uses the currently accepted scientific names of host species. Recent monographs and several specialists were consulted to determine current and correct specific, generic, and family designations. A search for a particular host would not be considered complete unless synonyms of the generic and specific names were also included in that search. Listing all synonyms of each host species is beyond the scope of this catalog, but we include some of the most common synonyms (those most often found in the literature on viral diseases) along with the accepted scientific names.



Usually, viral diseases have been reported as naturally occurring in their hosts ("natural hosts" or "typical hosts"). Sometimes, however, reports indicate that a disease resulted from inoculation with a virus originally isolated from another host. Thus, some records represent "accidental hosts" or "substitute hosts," i.e. although susceptible, hosts in which the virus is not commonly found. These few instances are not marked in the lists; thus accidental hosts cannot be identified. Information on host specificity (or host range) of the pathogens is contained in the master file.

We have been forced to lump several records in the ill-defined category "presumed virosis" (code 17). We believe that far too many papers are rushed into print before sufficient evidence on the viral nature and pathogenicity of "virus-like" particles has been obtained. Sometimes, the viral nature of these particles is only conjecture. Faced with the dilemma of ignoring or listing such records, we decided to include them, hoping that the viral nature of the particles would be confirmed in further studies. In the meantime, the reader should consider each code 17 entry with moderate scepticism.

As the number of reports dealing with viral diseases of insects, mites, and ticks has been increasing at an accelerated rate since 1960, publication of a comprehensive list of literature citations in a conventional format is now beyond the scope of this catalog. The printing costs alone for such an extensive bibliography would be prohibitive.

Several machine-readable bibliographic data bases have been developed that include records of viral diseases of arthropods. Journal articles, patents, technical reports, reviews, books, dissertations, monographs, and conference and symposium proceedings are covered. With formulation of appropriate keyword profiles, these data bases can be searched by public and private information services. Readers interested in literature citations should contact one or more of these services for further details. The following are listed as examples only: USDA, National Agricultural Library, Information Systems Division, 10301 Baltimore Boulevard, Beltsville, MD 20705, USA; Cambridge Scientific Abstracts, Database Services, 5161 River Road, Bethesda, MD 20816, USA; and Commonwealth Agricultural Bureaux, Farnham House, Farnham Royal, Slough SL2 3BN, United Kingdom.

## Diseases and Viral Agents

The disease names (see key, on last page) are those most commonly used in the English language. The selection of a disease name for our FAMULUS input reflects the information content of each publication. For instance, "polyhedrosis" (code 16) indicates that the author of a report did not specify whether the disease was a "cytoplasmic polyhedrosis" (code 5) or a "nuclear polyhedrosis" (code 12), and no cytological or histological evidence was presented in the publication (an omission not uncommon before 1960). "Hairless-black syndrome" (code 21) indicates that the author of the report discusses the syndrome as distinct from "bee chronic paralysis" (code 2), even though both paralysis and syndrome are caused by the same virus. "Presumed virosis" (code 17) indicates that the author of the report suspects a virus as the causative agent of the disease, but such a virus has not been isolated and the causal relation has not been proved. "Gattine" (code 8), a type of flacherie, is listed mainly because of the historical significance of the reports that mention it.

The reader is reminded that this is a catalog of diseases, not of viruses. The code numbers refer to diseases, syndromes, or disease groups. Disease names have remained stable over the years, whereas the names of the viral agents have changed, in some instances many times. For example, "polyhedrosis" has been in general use since 1906, and "nuclear polyhedrosis" since about 1950, but the name of nuclear polyhedrosis virus changed several times since 1906 (*Chlamydozoon*, 1907; *Crystalloplasma*, 1918; *Borrelina*, 1926; *Bollea*, 1953; *Borrelinavirus*, 1960; and, since 1971, *Baculovirus*). This state of affairs is not limited to nuclear polyhedrosis virus, but it occurs to some extent in other virus groups. Clearly, coding by disease rather than viral agents makes for a more stable reference list and possibly an internationally more acceptable format. If doubt arises as to a particular disease record, we can retrieve the original source from our data base and consult it for detailed information. Thus far, none of our colleagues has reported problems or ambiguities resulting from the use of the three previous editions of the catalog.

Since 1966, the International Committee on Taxonomy of Viruses (ICTV) has developed a sound framework for the nomenclature and classification of viruses. In view of the general approval accorded by virologists to this uniform taxonomy of viruses, we have included a table of the virus taxa approved by ICTV containing members pathogenic for or associated with the arthropods listed (table 1). The arrangement of families and groups is that currently approved by ICTV (Matthews 1982), with some modifications and additions planned for the next edition of the ICTV classification (C. C. Payne, ICTV, personal communication). Code numbers referring to viral diseases are given in parentheses after the name of each virus.

**Table 1—Families and groups of viruses associated with the arthropods listed in this catalog**

Virus	Code number for viral disease
DNA VIRUSES	
Double-stranded DNA, enveloped	
POXVIRIDAE, Poxviruses	
ENTOMOPOXVIRINAE, Poxviruses of insects	
Three probable genera	19
BACULOVIRIDAE	
<i>Baculovirus</i>	
Subgroup A, nuclear polyhedrosis virus	12
Subgroup B, granulosis virus	9
Subgroup C, enveloped nonoccluded rod-shaped nuclear virus	11, 13
POLYDNAVIRIDAE	
<i>Polydnavirus</i>	
Subgroup A, polydnavirus with fusiform nucleocapsids	13
Subgroup B, polydnavirus with rod-shaped nucleocapsids	13
Double-stranded DNA, nonenveloped	
IRIDOVIRIDAE, icosahedral cytoplasmic deoxyriboviruses	
<i>Iridovirus</i> , small iridescent insect virus	10
<i>Chloriridovirus</i> , large iridescent insect virus	10
Single-stranded DNA, nonenveloped	
PARVOVIRIDAE, parvoviruses	
<i>Densovirus</i> , densonucleosis virus	6
RNA VIRUSES	
Double-stranded RNA, nonenveloped	
REOVIRIDAE, reoviruses	
Cytoplasmic polyhedrosis virus	5, 14
BIRNAVIRIDAE, bisegmented dsRNA viruses	
<i>Birnavirus</i> , <i>Drosophila</i> X virus	13
Single-stranded RNA, enveloped	
RHABDOVIRIDAE, bullet-shaped viruses	
<i>Sigmavirus</i> , CO <sub>2</sub> sensitivity virus	3



**Table 1—Families and groups of viruses associated with the arthropods listed in this catalog (continued)**

Virus	Code number for viral disease
RNA VIRUSES	
Single-stranded RNA, nonenveloped	
PICORNAVIRIDAE, picornaviruses	
Cricket paralysis virus	13, 15
<i>Drosophila</i> C virus	13
<i>Gonometa</i> virus	13
Infectious flacherie virus	7
<i>Rhopalosiphum padi</i> virus	13
CALICIVIRIDAE, caliciviruses	
<i>Amyelois</i> chronic stunt virus	13
<i>Nudaurelia</i> $\beta$ virus group	
<i>Nudaurelia</i> $\beta$ virus	13
<i>Trichoplusia</i> RNA virus	13
Related viruses isolated from other Lepidoptera	13
NODAVIRIDAE	
<i>Nodavirus</i>	
Nodamura virus	13
Black beetle virus	13
Unclassified small spherical RNA viruses	
Arkansas bee virus	13
Bee acute paralysis virus	1
Bee chronic paralysis virus associate	2, 13
Bee slow paralysis virus	15
Bee virus X	13
Bee virus Y	13
Black queen cell virus	13
Cloudy wing virus	13
Crystalline array virus	4
<i>Drosophila</i> A virus	13
<i>Drosophila</i> P virus	13
Kashmir bee virus	13
Kelp fly virus	13
Sacbrood virus	18
Unclassified small ovoid RNA viruses	
Bee chronic paralysis virus	2, 21
<i>Drosophila</i> RS virus	13

**Table 1—Families and groups of viruses associated with the arthropods listed in this catalog (continued)**

Virus	Code number for viral disease
OTHER UNCLASSIFIED VIRUSES	
Rod-shaped, enveloped	
Cricket macronucleosis virus	13
<i>Hypera</i> virus	14
Long flexuous rod, enveloped	
Bee filamentous virus	22

## Acknowledgments

We thank those authors who, for many years, have given us reprints of their publications on viral diseases of arthropods. Without their important contribution, this catalog would not be nearly as comprehensive as it is. We are most indebted to those colleagues who notified us of errors and suggested new hosts and disease records. We gratefully acknowledge Christopher C. Payne, Glasshouse Crops Research Institute, Littlehampton, West Sussex, U.K., for his advice on viral taxonomy and for providing unpublished information.

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## **Appendix 1**

### **List of Hosts by Taxonomic Categories**





ORDER	FAMILY	GENUS	SPECIES	DISEASES
ACARI	ARGASIDAE	ARGAS	PERSICUS	17
ACARI	ARGASIDAE	ORNITHODOROS	LAHORENSIS	17
ACARI	ARGASIDAE	ORNITHODOROS	MOUBATA	17
ACARI	ARGASIDAE	ORNITHODOROS	TARTAKOVSKYI	17
ACARI	ARGASIDAE	ORNITHODOROS	THOLOZANI	17
ACARI	ARGASIDAE	ORNITHODOROS	VERRUCOSUS	17
ACARI	CAMISIIDAE	PLATYNOTHRUS	PELTIFER	17
ACARI	DAMAEIDAE	DAMAEUS	CLAVIPES	17
ACARI	EUPHTHRACARIDAE	MICROTRITIA	MINIMA	17
ACARI	IXODIDAE	BOOPHILUS	MICROPLUS	17
ACARI	IXODIDAE	DERMACENTOR	MARGINATUS	17
ACARI	PHTHIRACARIDAE	PHTHIRACARUS	GLOBOSUS	17
ACARI	PHYTOSEIIDAE	PHYTOSEIULUS	PERSIMILIS	17
ACARI	TETRANYCHIDAE	PANONYCHUS	CITRI	13 17
ACARI	TETRANYCHIDAE	PANONYCHUS	ULMI	13 17
ACARI	TETRANYCHIDAE	TETRANYCHUS	CINNABARINUS	13 17
ACARI	TETRANYCHIDAE	TETRANYCHUS	MULTISETIS	17
ACARI	TETRANYCHIDAE	TETRANYCHUS	TELARIUS	(SEE TETRANYCHUS URTICAE)
ACARI	TETRANYCHIDAE	TETRANYCHUS	URTICAE	17
COLEOPTERA	BUPRESTIDAE	AGRILUS	SUVOROVI POPULNEUS	5
COLEOPTERA	BUPRESTIDAE	MELANOPHILA	PICTA	5 16
COLEOPTERA	BUPRESTIDAE	TRACHYS	AURICOLLIS	10
COLEOPTERA	CERAMBYCIDAE	BATOCERA	LINEOLATA	12
COLEOPTERA	CERAMBYCIDAE	PLOCAEDERUS	FERRUGINEUS	11
COLEOPTERA	CERAMBYCIDAE	STENODRYAS	CLAVIGERA	10
COLEOPTERA	CERAMBYCIDAE	STENYGRINUM	QUADRINOTATUM	(SEE STENODRYAS CLAVIGERA)
COLEOPTERA	CERAMBYCIDAE	TETROPIUM	CINNAMOPTERUM	12
COLEOPTERA	CHRYSOMELIDAE	CEROTOMA	TRIFURCATA	17
COLEOPTERA	CHRYSOMELIDAE	CHRYSOMELA	VIGINTIPUNCTATA	10
COLEOPTERA	CHRYSOMELIDAE	COELAEENOMENODERA	MINUTA	13
COLEOPTERA	CHRYSOMELIDAE	DIABROTICA	UNDECIMPUNCTATA	13 17
COLEOPTERA	CHRYSOMELIDAE	LEPTINOTARSA	DECEMLINEATA	10
COLEOPTERA	CHRYSOMELIDAE	MICRODERA	VIGINTIPUNCTATA	(SEE CHRYSOMELA VIGINTIPUNCTATA)
COLEOPTERA	COCCINELLIDAE	COCCINELLA	SEPTEMPUNCTATA BRUCKII	10
COLEOPTERA	COCCINELLIDAE	EPILOCHNA	VARIIVESTIS	17
COLEOPTERA	CURCULIONIDAE	ANTHONOMUS	GRANDIS	10 12
COLEOPTERA	CURCULIONIDAE	CRYPTORHYNCHUS	MANGIFERAE	13
COLEOPTERA	CURCULIONIDAE	CURCULIO	DENTIPES	10
COLEOPTERA	CURCULIONIDAE	HYPERA	POSTICA	14
COLEOPTERA	CURCULIONIDAE	STERNOCHETUS	MANGIFERAE	(SEE CRYPTORHYNCHUS MANGIFERAE)
COLEOPTERA	DERMESTIDAE	ANTHRENUS	MUSEORUM	12 16
COLEOPTERA	DERMESTIDAE	DERMESTES	LARDARIUS	12 16
COLEOPTERA	GYRINIDAE	GYRINUS	NATATOR	13
COLEOPTERA	LUCANIDAE	FIGULUS	SUBLAEVIS	19
COLEOPTERA	LUCANIDAE	MACRODORCUS	RECTUS	10
COLEOPTERA	LUCANIDAE	MACRODORCUS	RUBROFEMORATUS	10
COLEOPTERA	SCARABAEIDAE	ALLOMYRINA	DICHOTOMUS	10
COLEOPTERA	SCARABAEIDAE	AMPHIMALLON	SOLSTITIALIS	19
COLEOPTERA	SCARABAEIDAE	ANOMALA	CUPREA	19
COLEOPTERA	SCARABAEIDAE	ANOPLOGNATHUS	POROSUS	19
COLEOPTERA	SCARABAEIDAE	ANOXIA	VILLOSA	19
COLEOPTERA	SCARABAEIDAE	ANTITROGUS	MORBILLOSUS	19
COLEOPTERA	SCARABAEIDAE	APHIDIUS	TASMANIAE	13 19
COLEOPTERA	SCARABAEIDAE	COSTELYTRA	ZEALANDICA	10 13
COLEOPTERA	SCARABAEIDAE	DASYGNATHUS	SP.	19
COLEOPTERA	SCARABAEIDAE	DEMODENA	BORANENSIS	19
COLEOPTERA	SCARABAEIDAE	DERMOLEPIDA	ALBOHIRTUM	19
COLEOPTERA	SCARABAEIDAE	GEOTRUPES	SILVATICUS	19
COLEOPTERA	SCARABAEIDAE	GEOTRUPES	STERCOROSUS	19
COLEOPTERA	SCARABAEIDAE	HETERONYCHUS	ARATOR	10 11 13
COLEOPTERA	SCARABAEIDAE	HOPLIA	SP.	19
COLEOPTERA	SCARABAEIDAE	MELOLONTHA	HIPPOCASTANI	20
COLEOPTERA	SCARABAEIDAE	MELOLONTHA	MELOLONTHA	6 19 20
COLEOPTERA	SCARABAEIDAE	ODONTRIA	SP.	10
COLEOPTERA	SCARABAEIDAE	OPOGONIA	SP.	10

ORDER	FAMILY	GENUS	SPECIES	DISEASES
COLEOPTERA	SCARABAEIDAE	ORYCTES	BOAS	11 20
COLEOPTERA	SCARABAEIDAE	ORYCTES	MONOCEROS	11 20
COLEOPTERA	SCARABAEIDAE	ORYCTES	NASICORNIS	11 20
COLEOPTERA	SCARABAEIDAE	ORYCTES	RHINOCEROS	11
COLEOPTERA	SCARABAEIDAE	OTHNONIUS	BATESI	19
COLEOPTERA	SCARABAEIDAE	PERICOPTUS	TRUNCATUS	13
COLEOPTERA	SCARABAEIDAE	PHYLLOPERTHA	HORTICOLA	19
COLEOPTERA	SCARABAEIDAE	PHYLLOPHAGA	ANXIA	17
COLEOPTERA	SCARABAEIDAE	PHYLLOPHAGA	PLEEI	19
COLEOPTERA	SCARABAEIDAE	PROAGOPERTHA	LUCIDULA	19
COLEOPTERA	SCARABAEIDAE	RHOPAEA	MORBILLOSA	(SEE ANTITROGUS MORBILLOSUM)
COLEOPTERA	SCARABAEIDAE	RHOPAEA	VERRAUXI	19
COLEOPTERA	SCARABAEIDAE	SCAPANES	AUSTRALIS GROSSEPUNCTATUS	11
COLEOPTERA	SCARABAEIDAE	SERICESTHIS	PRUNOSA	10
COLEOPTERA	SCARABAEIDAE	XYLOTROPUS	DICHOTOMUS	(SEE ALLOMYRINA DICHOTOMUS)
COLEOPTERA	SCOLYTIDAE	SCOLYTUS	SCOLYTUS	17
COLEOPTERA	TENEBRIONIDAE	TENEBRIO	MOLITOR	10 17
DIPTERA	BIBIONIDAE	BIBIO	MARCI	10
DIPTERA	CALLIPHORIDAE	CALLIPHORA	SP.	13
DIPTERA	CALLIPHORIDAE	CALLIPHORA	VOMITORIA	10 12 16
DIPTERA	CALLIPHORIDAE	PHORMIA	SP.	13
DIPTERA	CECIDOMYIIDAE	CONTARINIA	TRITICI	16
DIPTERA	CECIDOMYIIDAE	SITODIPLOSI	MOSELLANA	16
DIPTERA	CERATOPOGONIDAE	BEZZIA	PYGMAEA	10
DIPTERA	CERATOPOGONIDAE	CULICOIDES	ARBORICOLA	10
DIPTERA	CERATOPOGONIDAE	CULICOIDES	CAVATICUS	13
DIPTERA	CERATOPOGONIDAE	CULICOIDES	CLASTRIERI	10
DIPTERA	CERATOPOGONIDAE	CULICOIDES	CUBITALIS	10
DIPTERA	CERATOPOGONIDAE	CULICOIDES	ODIBILIS	10
DIPTERA	CERATOPOGONIDAE	CULICOIDES	SP.	5 10
DIPTERA	CHAOBORIDAE	CHAOBORUS	CRYSTALLINUS	13
DIPTERA	CHAOBORIDAE	CORETHRELLA	APPENDICULATA	10
DIPTERA	CHAOBORIDAE	CORETHRELLA	BRAKELEYI	10
DIPTERA	CHAOBORIDAE	MOCHLONYX	CULICIFORMIS	(SEE MOCHLONYX VELUTINUS)
DIPTERA	CHAOBORIDAE	MOCHLONYX	VELUTINUS	10
DIPTERA	CHIRONOMIDAE	CAMPTOCHIRONOMUS	TENTANS	(SEE CHIRONOMUS TENTANS)
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	ATTENUATUS	19
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	DECORUS	19
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	LURIDUS	19
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	PLUMOSUS	5 10
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	TENTANS	12 17 19
DIPTERA	CHIRONOMIDAE	GOELDICHIRONOMUS	HOLOPRASINUS	5 17 19
DIPTERA	COELOPIDAE	CHAEOTOCOELOPA	SYDNEYENSIS	13
DIPTERA	COELOPIDAE	COELOPA	FRIGIDA	17
DIPTERA	CULICIDAE	AEDES	AEGYPTI	5 6 10 12 13 17 19
DIPTERA	CULICIDAE	AEDES	ALBOPICTUS	6 10 11 13
DIPTERA	CULICIDAE	AEDES	ANNANDALEI	12
DIPTERA	CULICIDAE	AEDES	ANNULIPES	10
DIPTERA	CULICIDAE	AEDES	ATROPALPUS	12
DIPTERA	CULICIDAE	AEDES	CANTANS	6 10
DIPTERA	CULICIDAE	AEDES	CANTATOR	5
DIPTERA	CULICIDAE	AEDES	CASPIUS	10
DIPTERA	CULICIDAE	AEDES	CASPIUS CASPIUS	10
DIPTERA	CULICIDAE	AEDES	CASPIUS DORSALIS	(SEE AEDES DORSALIS)
DIPTERA	CULICIDAE	AEDES	CATAPHYLLA	10
DIPTERA	CULICIDAE	AEDES	CINEREUS	6
DIPTERA	CULICIDAE	AEDES	DETRITUS	10
DIPTERA	CULICIDAE	AEDES	DORSALIS	6 10 13
DIPTERA	CULICIDAE	AEDES	EPACTIUS	12
DIPTERA	CULICIDAE	AEDES	EXCRUCIANS	10
DIPTERA	CULICIDAE	AEDES	FLAVESCENS	10 19
DIPTERA	CULICIDAE	AEDES	FULVUS PALLENS	10
DIPTERA	CULICIDAE	AEDES	GENICULATUS	6
DIPTERA	CULICIDAE	AEDES	MELANIMON	13
DIPTERA	CULICIDAE	AEDES	NIGROMACULIS	12
DIPTERA	CULICIDAE	AEDES	PSEUDOSCUCELLARIS	17



ORDER	FAMILY	GENUS	SPECIES	DISEASES
DIPTERA	CULICIDAE	AEDES	SCUTELLARIS	12
DIPTERA	CULICIDAE	AEDES	SIERRENSIS	5 10
DIPTERA	CULICIDAE	AEDES	SOLLICITANS	5 10 12
DIPTERA	CULICIDAE	AEDES	STICTICUS	5 10
DIPTERA	CULICIDAE	AEDES	STIMULANS	10
DIPTERA	CULICIDAE	AEDES	STRAMINEUS	10
DIPTERA	CULICIDAE	AEDES	TAENIORHYNCHUS	5 10 12 13
DIPTERA	CULICIDAE	AEDES	THIBAULTI	5
DIPTERA	CULICIDAE	AEDES	TORMENTOR	12
DIPTERA	CULICIDAE	AEDES	TRISERIATUS	5 12 13 17
DIPTERA	CULICIDAE	AEDES	VEXANS	6 10
DIPTERA	CULICIDAE	ANOPHELES	ALBIMANUS	10 19
DIPTERA	CULICIDAE	ANOPHELES	BRADLEYI	5
DIPTERA	CULICIDAE	ANOPHELES	CRUCIANS	5 12
DIPTERA	CULICIDAE	ANOPHELES	FREEBORNI	5
DIPTERA	CULICIDAE	ANOPHELES	QUADRIMACULATUS	5 10 14
DIPTERA	CULICIDAE	ANOPHELES	STEPHENSI	3 5 13
DIPTERA	CULICIDAE	ANOPHELES	SUBPICTUS	17
DIPTERA	CULICIDAE	CULEX	ERRATICUS	5
DIPTERA	CULICIDAE	CULEX	MOLESTUS	(SEE CULEX PIPIENS MOLESTUS)
DIPTERA	CULICIDAE	CULEX	PECCATOR	5 10
DIPTERA	CULICIDAE	CULEX	PIPIENS	3 5
DIPTERA	CULICIDAE	CULEX	PIPIENS FATIGANS	(SEE C. PIPIENS QUINQUEFASCIATUS)
DIPTERA	CULICIDAE	CULEX	PIPIENS MOLESTUS	6 19
DIPTERA	CULICIDAE	CULEX	PIPIENS PIPIENS	5 6
DIPTERA	CULICIDAE	CULEX	PIPIENS QUINQUEFASCIATUS	3 10 12
DIPTERA	CULICIDAE	CULEX	RESTUANS	5 17
DIPTERA	CULICIDAE	CULEX	SALINARIUS	5 10 12 17
DIPTERA	CULICIDAE	CULEX	TAKSALIS	5 13 17
DIPTERA	CULICIDAE	CULEX	TERRITANS	5 10 17
DIPTERA	CULICIDAE	CULISETA	ANNULATA	6 10
DIPTERA	CULICIDAE	CULISETA	INORNATA	5 10 13
DIPTERA	CULICIDAE	CULISETA	MELANURA	5 10
DIPTERA	CULICIDAE	CULISETA	MORSITANS	10
DIPTERA	CULICIDAE	ERETMAPODITES	QUINQUEVITTATUS	12
DIPTERA	CULICIDAE	ORTHOPODOMYIA	SIGNIFERA	5 17
DIPTERA	CULICIDAE	PSOROPHORA	CONFINNIS	5 10 12 17
DIPTERA	CULICIDAE	PSOROPHORA	FEROX	5 10 12
DIPTERA	CULICIDAE	PSOROPHORA	HORRIDA	10
DIPTERA	CULICIDAE	PSOROPHORA	VARIPES	10 12
DIPTERA	CULICIDAE	TOXORHYNCHITES	AMBOINENSIS	3 13
DIPTERA	CULICIDAE	TOXORHYNCHITES	BREVIPALPIS	12
DIPTERA	CULICIDAE	URANOTAENIA	SAPPHIRINA	5 12 17
DIPTERA	CULICIDAE	WYEOMYIA	SMITHII	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	AFFINIS	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ALGONQUIN	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ANANASSAE	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ATHABASCA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	AZTECA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	BIFASCIATA	17
DIPTERA	DROSOPHILIDAE	DROSOPHILA	BUSCKII	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ERECTA	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	FASCIATA	(SEE DROSOPHILA MELANOGASTER)
DIPTERA	DROSOPHILIDAE	DROSOPHILA	FUNEBRIS	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	GIBBEROSA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	HYDEI	3 13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	IMMIGRANS	3 13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MACROSPINA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MACROSPINA LIMPIENSIS	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MALERKOTLIANA	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MAURITIANA	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MELANOGASTER	3 13 15 17
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MONTIUM	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	NASUTA	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	NEBULOSA	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PALLIDIPENNIS	3

ORDER	FAMILY	GENUS	SPECIES	DISEASES
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PAULISTORUM	13 17
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PROSALTANS	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PSEUDOOBSCURA	3 17
DIPTERA	DROSOPHILIDAE	DROSOPHILA	REPLETA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ROBUSTA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	SIMULANS	3 13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	TEISSIERI	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	TOLTECA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	VIRILIS	13 17
DIPTERA	DROSOPHILIDAE	DROSOPHILA	WILLISTONI	3 13 17
DIPTERA	DROSOPHILIDAE	DROSOPHILA	YAKUBA	13
DIPTERA	DROSOPHILIDAE	ZAPRIONUS	TUBERCULATUS	13
DIPTERA	MUSCIDAE	GLOSSINA	FUSCIPES FUSCIPES	17
DIPTERA	MUSCIDAE	GLOSSINA	MORSITANS CENTRALIS	17
DIPTERA	MUSCIDAE	GLOSSINA	MORSITANS MORSITANS	17
DIPTERA	MUSCIDAE	GLOSSINA	MORSITANS ORIENTALIS	17
DIPTERA	MUSCIDAE	GLOSSINA	PALLIDIPES	17
DIPTERA	MUSCIDAE	MUSCA	DOMESTICA	3 13
DIPTERA	SCIARIDAE	RHYNCHOSCIARA	ANGELAE	12 17
DIPTERA	SCIARIDAE	RHYNCHOSCIARA	HOLLAENDERI	12
DIPTERA	SCIARIDAE	RHYNCHOSCIARA	MILLERI	12
DIPTERA	SIMULIIDAE	CNEPHIA	MUTATA	5
DIPTERA	SIMULIIDAE	ODAGMIA	ORNATA	10
DIPTERA	SIMULIIDAE	PROSIMULIUM	MIXTUM	5
DIPTERA	SIMULIIDAE	PROSIMULIUM	MIXTUM FUSCUM	5
DIPTERA	SIMULIIDAE	SIMULIUM	ARGYREATUM	5
DIPTERA	SIMULIIDAE	SIMULIUM	AUREUM	5
DIPTERA	SIMULIIDAE	SIMULIUM	CALLIDUM	10
DIPTERA	SIMULIIDAE	SIMULIUM	EARLEI	10
DIPTERA	SIMULIIDAE	SIMULIUM	METALLICUM	10
DIPTERA	SIMULIIDAE	SIMULIUM	ORNATUM	10
DIPTERA	SIMULIIDAE	SIMULIUM	RUBICUNDULUM	(SEE SIMULIUM VIRGATUM)
DIPTERA	SIMULIIDAE	SIMULIUM	SP.	10
DIPTERA	SIMULIIDAE	SIMULIUM	TUBEROSUM	5
DIPTERA	SIMULIIDAE	SIMULIUM	VENUSTUM	5
DIPTERA	SIMULIIDAE	SIMULIUM	VIRGATUM	10
DIPTERA	SIMULIIDAE	SIMULIUM	VITTATUM	5 6
DIPTERA	SIMULIIDAE	STEGOPTERNA	MUTATA	(SEE CNEPHIA MUTATA)
DIPTERA	SYRPHIDAE	MERODON	EQUESTRIS	13
DIPTERA	TACHINIDAE	EXORISTA	SORBILLANS	10
DIPTERA	TACHINIDAE	UGYMYIA	SERICARIAE	12
DIPTERA	TEPHRITIDAE	CERATITIS	CAPITATA	3 13
DIPTERA	TEPHRITIDAE	DACUS	TRYONI	14
DIPTERA	TIPULIDAE	TIPULA	LIVIDA	10
DIPTERA	TIPULIDAE	TIPULA	OLERACEA	10
DIPTERA	TIPULIDAE	TIPULA	PALUDOSA	10 12 16
HEMIPTERA	APHIDIDAE	APHIS	SP.	17
HEMIPTERA	APHIDIDAE	MYZUS	PERSICAE	17
HEMIPTERA	APHIDIDAE	PENTALONIA	NIGRONERVOSA	17
HEMIPTERA	APHIDIDAE	RHOPALOSIPHUM	MAIDIS	17
HEMIPTERA	APHIDIDAE	RHOPALOSIPHUM	PADI	13 17
HEMIPTERA	APHIDIDAE	RHOPALOSIPHUM	RUFIABDOMINALIS	13
HEMIPTERA	APHIDIDAE	SCHIZAPHIS	GRAMINUM	13
HEMIPTERA	BELOSTOMATIDAE	LETHOCERUS	COLUMBIAE	10
HEMIPTERA	CICADELLIDAE	COLLADONUS	MONTANUS	10
HEMIPTERA	CICADELLIDAE	NEPHOTETIX	CINCTICEPS	10
HEMIPTERA	DELPHACIDAE	LAODELPHAX	STRIATELLA	10
HEMIPTERA	DELPHACIDAE	TAKOPHAGUS	PROSERPINA	17
HEMIPTERA	REDUVIIDAE	PANSTRONGYLUS	MEGISTUS	17
HEMIPTERA	REDUVIIDAE	TRIATOMA	INFESTANS	17
HYMENOPTERA	APIDAE	APIS	CERANA	10 13 18
HYMENOPTERA	APIDAE	APIS	MELLIFERA	1 2 6 10 13 15 17 18 21 22
HYMENOPTERA	APIDAE	BOMBUS	AGRORUM	1
HYMENOPTERA	APIDAE	BOMBUS	FERVIDUS	19
HYMENOPTERA	APIDAE	BOMBUS	HORTORUM	1
HYMENOPTERA	APIDAE	BOMBUS	IMPATIENS	19

ORDER	FAMILY	GENUS	SPECIES	DISEASES
HYMENOPTERA	APIDAE	BOMBUS	LUCORUM	1 15
HYMENOPTERA	APIDAE	BOMBUS	PENNSYLVANICUS	19
HYMENOPTERA	APIDAE	BOMBUS	RUDERARIUS	1
HYMENOPTERA	APIDAE	BOMBUS	TERRESTRIS	1
HYMENOPTERA	ARGIDAE	ARGE	PECTORALIS	9 12
HYMENOPTERA	BRACONIDAE	APANTELES	CONGREGATUS	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	CRASSICORNIS	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	FLAVIPES	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	FUMIFERANAE	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	GLOMERATUS	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	HYPHANTRIAE	13
HYMENOPTERA	BRACONIDAE	APANTELES	LIPARIDIS	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	MARGINIVENTRIS	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	MELANOSCELUS	(SEE COTESIA MELANOSCELA)
HYMENOPTERA	BRACONIDAE	APANTELES	ORNIGIS	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	PALEACRITAE	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	RUBECULA	13
HYMENOPTERA	BRACONIDAE	ASCOGASTER	ARGENTIFRONS	13
HYMENOPTERA	BRACONIDAE	ASCOGASTER	QUADRIDENTATA	13
HYMENOPTERA	BRACONIDAE	CARDIOCHILES	NIGRICEPS	13 17
HYMENOPTERA	BRACONIDAE	CHELONUS	ALTITUDINIS	13
HYMENOPTERA	BRACONIDAE	CHELONUS	BLACKBURNI	13
HYMENOPTERA	BRACONIDAE	CHELONUS	TEXANUS	13 17
HYMENOPTERA	BRACONIDAE	COTESIA	MELANOSCELA	13 17
HYMENOPTERA	BRACONIDAE	HYPOMICROGASTER	ECDYTOLOPHAE	13
HYMENOPTERA	BRACONIDAE	MICROGASTER	CANADENSIS	13
HYMENOPTERA	BRACONIDAE	MICROPLITIS	CROCEIPES	13 17
HYMENOPTERA	BRACONIDAE	PHANEROTOMA	FLAVITESTACEA	13 17
HYMENOPTERA	BRACONIDAE	PROTOMICROPLITIS	FACETOSA	13
HYMENOPTERA	DIPRIONIDAE	DIPRION	HERCYNIAE	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	LEUWANENSIS	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	NIPPONICA	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	PALLIDA	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	PINDROWI	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	PINI	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	POLYTOMA	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	SIMILIS	12
HYMENOPTERA	DIPRIONIDAE	GILPINIA	HERCYNIAE	(SEE DIPRION HERCYNIAE)
HYMENOPTERA	DIPRIONIDAE	LOPHYRUS	RUFUS	(SEE NEODIPRION SERTIFER)
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	ABIETIS	12 16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	AMERICANUM	(SEE NEODIPRION TAEDAE TAEDAE)
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	EXCITANS	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	LECONTEI	12 16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	MERKELI	5
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	MUNDUS	16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	NANULUS	16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	NANULUS CONTORTAE	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	PRATTI BANKSIANAE	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	PRATTI PRATTI	16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	SERTIFER	12 16 17
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	SWAINI	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	TAEDAE LINEARIS	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	TAEDAE TAEDAE	12 16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	TSUGAE	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	VIRGINIANA	12
HYMENOPTERA	DIPRIONIDAE	TENTHREDO	SERTIFERA	(SEE NEODIPRION SERTIFER)
HYMENOPTERA	FORMICIDAE	FORMICA	LUGUBRIS	17
HYMENOPTERA	FORMICIDAE	IRIDOMYRMEX	ITOI	10
HYMENOPTERA	FORMICIDAE	LEPTOTHORAX	CONGRUUS	13
HYMENOPTERA	FORMICIDAE	SOLENOPSIS	GEMINATA	17
HYMENOPTERA	FORMICIDAE	SOLENOPSIS	SP.	17
HYMENOPTERA	HALICTIDAE	NOMIA	MELANDERI	17
HYMENOPTERA	ICHNEUMONIDAE	BATHYPLECTES	CURCULIONIS	13
HYMENOPTERA	ICHNEUMONIDAE	CAMPOLETIS	FLAVICINCTA	13
HYMENOPTERA	ICHNEUMONIDAE	CAMPOLETIS	SONORENSIS	13 17
HYMENOPTERA	ICHNEUMONIDAE	CAMPOPLEX	SP.	13



ORDER	FAMILY	GENUS	SPECIES	DISEASES
HYMENOPTERA	ICHNEUMONIDAE	CASINARIA	INFESTA	13
HYMENOPTERA	ICHNEUMONIDAE	CASINARIA	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	DEVORGILLA	SP.	(SEE VENTURIA SP.)
HYMENOPTERA	ICHNEUMONIDAE	DIADEGMA	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	ERIBORUS	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	GLYPTA	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	HOROGENES	SP.	(SEE DIADEGMA SP.)
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	ANNULIPES	13
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	EXIGUAE	13 17
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	FUGITIVUS FUGITIVUS	13
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	PILOSULUS	13
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	MESOLEIUS	TENTHREDINIS	13
HYMENOPTERA	ICHNEUMONIDAE	NEMERITIS	SP.	(SEE VENTURIA SP.)
HYMENOPTERA	ICHNEUMONIDAE	OLESICAMPE	BENEFACTOR	13
HYMENOPTERA	ICHNEUMONIDAE	TRANOSEMA	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	VENTURIA	CANESCENS	13
HYMENOPTERA	ICHNEUMONIDAE	VENTURIA	SP.	13
HYMENOPTERA	MEGACHILIDAE	MEGACHILE	ROTUNDATA	2 5 13 17
HYMENOPTERA	PAMPHILIIDAE	ACANTHOLYDA	ERYTHROCEPHALA	12
HYMENOPTERA	PAMPHILIIDAE	ACANTHOLYDA	NEMORALIS	16
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	ABIETIS	12 16
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	ALPINA	16
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	FASCIPENNIS	9
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	ISSIKI	12
HYMENOPTERA	PAMPHILIIDAE	CEPHALEIA	LARICIPHILA	(SEE CEPHALCIA ALPINA)
HYMENOPTERA	PAMPHILIIDAE	LYDA	CAMPESTRIS	(SEE CEPHALCIA ABIETIS)
HYMENOPTERA	PAMPHILIIDAE	LYDA	HYPOTROPHICA	(SEE CEPHALCIA ABIETIS)
HYMENOPTERA	PAMPHILIIDAE	LYDA	STELLATA	(SEE ACANTHOLYDA NEMORALIS)
HYMENOPTERA	PAMPHILIIDAE	TENTHREDO	PRATENSIS	(SEE ACANTHOLYDA NEMORALIS)
HYMENOPTERA	SIRICIDAE	SIREX	JUVENCUS	5
HYMENOPTERA	SIRICIDAE	SIREX	NOCTILIO	5
HYMENOPTERA	SIRICIDAE	UROCERUS	GIGAS GIGAS	5
HYMENOPTERA	SIRICIDAE	UROCERUS	TARDIGRADUS	5
HYMENOPTERA	SIRICIDAE	XERIS	SPECTRUM	5
HYMENOPTERA	TENTHREDINIDAE	ANOPLONYX	DESTRUCTOR	5
HYMENOPTERA	TENTHREDINIDAE	CLADIUS	VIMINALIS	(SEE TRICHIOCAMPUS VIMINALIS)
HYMENOPTERA	TENTHREDINIDAE	HEMICHROA	CROCEA	12
HYMENOPTERA	TENTHREDINIDAE	MESONEURA	RUFONOTA	12
HYMENOPTERA	TENTHREDINIDAE	NEMATUS	OLFACIENS	12
HYMENOPTERA	TENTHREDINIDAE	PIKONEMA	DIMOCKII	12
HYMENOPTERA	TENTHREDINIDAE	PRISTIPHORA	ERICHSONII	12 16
HYMENOPTERA	TENTHREDINIDAE	PRISTIPHORA	GENICULATA	12
HYMENOPTERA	TENTHREDINIDAE	TRICHIOCAMPUS	IRREGULARIS	12
HYMENOPTERA	TENTHREDINIDAE	TRICHIOCAMPUS	VIMINALIS	12
HYMENOPTERA	VESPIDAE	DOLICHOVESPUA	MEDIA	15
HYMENOPTERA	VESPIDAE	VESPA	CRABRO	15
HYMENOPTERA	VESPIDAE	VESPULA	VULGARIS	15
HYMENOPTERA	XYLOCOPIIDAE	XYLOCOPA	VIOLACEA	15
ISOPTERA	MACROTHERMITIDAE	ODONTOTERMES	FORMOSANUS	13
ISOPTERA	RHINOTERMITIDAE	COPTOTERMES	LACTEUS	17
ISOPTERA	TERMITIDAE	NASUTITERMES	EXITIOSUS	13 15 17
ISOPTERA	TERMOPSIDAE	POROTERMES	ADAMSONI	17
LEPIDOPTERA	AGARISTIDAE	PHALAENOIDES	GLYCINAE	9 13
LEPIDOPTERA	ANTHELIDAE	ANTHELA	VARIA	12
LEPIDOPTERA	ANTHELIDAE	PTEROLOCERA	AMPLICORNIS	12
LEPIDOPTERA	ARCTIIDAE	ALPHAEA	PHASMA	12
LEPIDOPTERA	ARCTIIDAE	AMSACTA	ALBISTRIGA	12
LEPIDOPTERA	ARCTIIDAE	AMSACTA	LACTINEA	9 12
LEPIDOPTERA	ARCTIIDAE	AMSACTA	MOOREI	12 19
LEPIDOPTERA	ARCTIIDAE	AMSACTA	SP.	12
LEPIDOPTERA	ARCTIIDAE	APANTESIS	VIRGO	16
LEPIDOPTERA	ARCTIIDAE	ARCTIA	CAJA	5 12 16
LEPIDOPTERA	ARCTIIDAE	ARCTIA	VILLICA	5 12
LEPIDOPTERA	ARCTIIDAE	ARDICES	GLATIGNYI	12
LEPIDOPTERA	ARCTIIDAE	CALLIMORPHA	QUADRIPUNCTARIA	(SEE EUPLAGIA QUADRIPUNCTARIA)

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	ARCTIIDAE	CYCNIA	MENDICA	(SEE DIAPHORA MENDICA)
LEPIDOPTERA	ARCTIIDAE	DIACRISIA	OBLIQUA	9 12
LEPIDOPTERA	ARCTIIDAE	DIACRISIA	PURPURATA	5 12
LEPIDOPTERA	ARCTIIDAE	DIACRISIA	VIRGINICA	5 9 12
LEPIDOPTERA	ARCTIIDAE	DIAPHORA	MENDICA	5 12
LEPIDOPTERA	ARCTIIDAE	DIONYCHOPUS	AMASIS	9 13
LEPIDOPTERA	ARCTIIDAE	ECPANTHERIA	ICASIA	9 12
LEPIDOPTERA	ARCTIIDAE	ESTIGMENE	ACREA	5 9 10 12 16 19
LEPIDOPTERA	ARCTIIDAE	EUPLAGIA	QUADRIPUNCTARIA	5 13
LEPIDOPTERA	ARCTIIDAE	HALISIDOTA	ARGENTATA	12
LEPIDOPTERA	ARCTIIDAE	HALISIDOTA	CARYAE	12
LEPIDOPTERA	ARCTIIDAE	HYPHANTRIA	CUNEA	5 9 12 16
LEPIDOPTERA	ARCTIIDAE	HYPOCRITA	JACOBAAEAE	5 12 13
LEPIDOPTERA	ARCTIIDAE	ISIA	ISABELLA	5
LEPIDOPTERA	ARCTIIDAE	OCNOGYNA	LOEWII	17
LEPIDOPTERA	ARCTIIDAE	PANAXIA	DOMINULA	5 12
LEPIDOPTERA	ARCTIIDAE	PARASEMIA	PLANTAGINIS	5
LEPIDOPTERA	ARCTIIDAE	PERICALLIA	RICINI	9 12
LEPIDOPTERA	ARCTIIDAE	PHRAGMATOBIA	FULIGINOSA	5 9 16
LEPIDOPTERA	ARCTIIDAE	RHYPARIA	PURPURATA	(SEE DIACRISIA PURPURATA)
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	FLAMMEOLUS	10
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	IMPARILIS	(SEE SPILOSOMA LUBRICIPEDA)
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	LUBRICIPEDA	(SEE SPILOSOMA LUBRICIPEDA)
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	SUBCARNEA	5 12
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	LUBRICIPEDA	5 10 12
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	LUTEA	5
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	MENTHASTRI	(SEE SPILOSOMA LUBRICIPEDA)
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	PUNCTARIA	5 10
LEPIDOPTERA	ARCTIIDAE	TYRIA	JACOBAAEAE	(SEE HYPOCRITA JACOBAAEAE)
LEPIDOPTERA	ARGYRESTHIDAE	ARGYRESTHIA	CONJUGELLA	12
LEPIDOPTERA	ARGYRESTHIDAE	ARGYRESTHIA	CUPRESSELLA	9
LEPIDOPTERA	BOMBYCIDAE	BOMBYX	MORI	5 6 7 8 10 12 13 14 19
LEPIDOPTERA	BOMBYCIDAE	OCINARA	VARIANS	12
LEPIDOPTERA	BOMBYCIDAE	RONDIOTIA	MENCIANA	12
LEPIDOPTERA	BOMBYCIDAE	THEOPHILA	MANDARINA	5 12
LEPIDOPTERA	BRASSOLIDAE	OPSIPHANES	CASSINA	12
LEPIDOPTERA	CARPOSINIDAE	CARPOSINA	NIPONENSIS	9 12
LEPIDOPTERA	COCHYLIDAE	CLYSIANA	AMBIGUELLA	(SEE EUPOECILIA AMBIGUELLA)
LEPIDOPTERA	COCHYLIDAE	EUPOECILIA	AMBIGUELLA	16
LEPIDOPTERA	COCYTIIDAE	EUCOCYTIS	MEEKI	13
LEPIDOPTERA	COLEOPHORIDAE	COLEOPHORA	LARICELLA	12
LEPIDOPTERA	COSSIDAE	COSSUS	COSSUS	12
LEPIDOPTERA	CRYPTOPHASIDAE	NEPHANTIS	SERINOPA	(SEE OPISINA ARENOSELLA)
LEPIDOPTERA	CRYPTOPHASIDAE	OPISINA	ARENOSELLA	12
LEPIDOPTERA	DANAIDAE	DANAUS	PLEXIPPUS	5 16 17
LEPIDOPTERA	DANAIDAE	EUPLOEA	COREA	13
LEPIDOPTERA	DIOPTIDAE	PHRYGANIDIA	CALIFORNICA	12
LEPIDOPTERA	DREPANIDAE	DREPANA	LACERTINARIA	5
LEPIDOPTERA	ETHMIDAE	ETHMIA	ASSAMENSIS	10
LEPIDOPTERA	EUPTEROTIDAE	ANDRACA	BIPUNCTATA	9
LEPIDOPTERA	GELECHIIDAE	APROAEREMA	MODICELLA	12
LEPIDOPTERA	GELECHIIDAE	BRACHMIA	MACROSCOPA	10
LEPIDOPTERA	GELECHIIDAE	COLEOTECHNITES	MILLERI	9
LEPIDOPTERA	GELECHIIDAE	GNORIMOSCHEMA	OPERCULELLA	(SEE PHTHORIMAEA OPERCULELLA)
LEPIDOPTERA	GELECHIIDAE	PECTINOPHORA	GOSSYPIELLA	5 12
LEPIDOPTERA	GELECHIIDAE	PHTHORIMAEA	OPERCULELLA	9 12
LEPIDOPTERA	GELECHIIDAE	RECURVARIA	MILLERI	(SEE COLEOTECHNITES MILLERI)
LEPIDOPTERA	GELECHIIDAE	STOMOPTERYX	SUBSESCIVELLA	(SEE APROAEREMA MODICELLA)
LEPIDOPTERA	GEOMETRIDAE	ABRAXAS	GROSSULARIATA	5 12
LEPIDOPTERA	GEOMETRIDAE	ACIDALIA	CARTICCARIA	12
LEPIDOPTERA	GEOMETRIDAE	ALSPHILA	POMETARIA	5 9 12
LEPIDOPTERA	GEOMETRIDAE	AMPHIDASIS	COGNATARIA	12
LEPIDOPTERA	GEOMETRIDAE	ANAITIS	PLAGIATA	5 12
LEPIDOPTERA	GEOMETRIDAE	ANTHELIA	HYPERBOREA	12
LEPIDOPTERA	GEOMETRIDAE	APOCHEIMA	CINERARIUS	12
LEPIDOPTERA	GEOMETRIDAE	APOCHEIMA	PILOSARIA	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	GEOMETRIDAE	BISTON	BETULARIA	5 12
LEPIDOPTERA	GEOMETRIDAE	BISTON	HIRTARIA	12
LEPIDOPTERA	GEOMETRIDAE	BISTON	HISPIDARIA	12
LEPIDOPTERA	GEOMETRIDAE	BISTON	MARGINATA	12 16
LEPIDOPTERA	GEOMETRIDAE	BISTON	ROBUSTUM	12
LEPIDOPTERA	GEOMETRIDAE	BISTON	STRATARIA	12
LEPIDOPTERA	GEOMETRIDAE	BOARMIA	BISTORTATA	12
LEPIDOPTERA	GEOMETRIDAE	BUPALUS	PINIARIUS	5 12 16
LEPIDOPTERA	GEOMETRIDAE	BUZURA	SUPPRESSARIA	12
LEPIDOPTERA	GEOMETRIDAE	BUZURA	THIBTARIA	12
LEPIDOPTERA	GEOMETRIDAE	CALOSPILOS	MIRANDA	10
LEPIDOPTERA	GEOMETRIDAE	CARECOMOTIS	REPULSARIA	10
LEPIDOPTERA	GEOMETRIDAE	CARIPETA	DIVISATA	12
LEPIDOPTERA	GEOMETRIDAE	CINGILIA	CATENARIA	12
LEPIDOPTERA	GEOMETRIDAE	CLEORA	RIBEATA	(SEE DEILEPTENIA RIBEATA)
LEPIDOPTERA	GEOMETRIDAE	CLEORA	SECUNDARIA	17
LEPIDOPTERA	GEOMETRIDAE	CROCALLIS	ELINGUARIA	5
LEPIDOPTERA	GEOMETRIDAE	CULCULA	PANTERINARIA	12
LEPIDOPTERA	GEOMETRIDAE	CYSTIDIA	STRATONICE STRATONICE	10
LEPIDOPTERA	GEOMETRIDAE	DEILEPTENIA	RIBEATA	12
LEPIDOPTERA	GEOMETRIDAE	ECTROPIS	CREPUSCULARIA	12 16
LEPIDOPTERA	GEOMETRIDAE	ECTROPIS	OBLIQUA	9 12
LEPIDOPTERA	GEOMETRIDAE	ENNOMOS	QUERCARIA	12
LEPIDOPTERA	GEOMETRIDAE	ENNOMOS	QUERCINARIA	12
LEPIDOPTERA	GEOMETRIDAE	ENNOMOS	SUBSIGNARIUS	12
LEPIDOPTERA	GEOMETRIDAE	ENYPIA	VENATA	12
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	ANKERARIA	12
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	DEFOLIARIA	12
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	TILIARIA	5 12
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	VANCOUVERENSIS	12
LEPIDOPTERA	GEOMETRIDAE	EULYPE	HASTATA	(SEE RHEUMAPTERA HASTATA)
LEPIDOPTERA	GEOMETRIDAE	EUPITHECIA	ANNULATA	12
LEPIDOPTERA	GEOMETRIDAE	EUPITHECIA	LONGIPALPATA	12
LEPIDOPTERA	GEOMETRIDAE	GLENA	BISULCA	9
LEPIDOPTERA	GEOMETRIDAE	GONODONTIS	ARIDA	10
LEPIDOPTERA	GEOMETRIDAE	HESPERUMIA	SULPHURARIA	12
LEPIDOPTERA	GEOMETRIDAE	HETEROLOCHA	ARISTONARIA NIPHONICA	10
LEPIDOPTERA	GEOMETRIDAE	HIBERNIA	DEFOLIARIA	(SEE ERANNIS DEFOLIARIA)
LEPIDOPTERA	GEOMETRIDAE	HYDRIA	PRUNIVORATA	9
LEPIDOPTERA	GEOMETRIDAE	HYDRIOMENA	IRATA	12
LEPIDOPTERA	GEOMETRIDAE	HYDRIOMENA	NUBILOFASCIATA	12
LEPIDOPTERA	GEOMETRIDAE	HYPERETIS	AMICARIA	12
LEPIDOPTERA	GEOMETRIDAE	JANKOWSKIA	ATHLETA	12
LEPIDOPTERA	GEOMETRIDAE	LAMBDA	FISCELLARIA	12 16
LEPIDOPTERA	GEOMETRIDAE	LAMBDA	FISCELLARIA LUGUBROSA	9 12 16
LEPIDOPTERA	GEOMETRIDAE	LAMBDA	FISCELLARIA SOMNIARIA	9 12 16
LEPIDOPTERA	GEOMETRIDAE	MELANOLOPHIA	IMITATA	12
LEPIDOPTERA	GEOMETRIDAE	MYRTETA	TINAGMARIA	12
LEPIDOPTERA	GEOMETRIDAE	NEMATOCAMPA	FILAMENTARIA	9
LEPIDOPTERA	GEOMETRIDAE	NEPYTIA	CANOSARIA	16
LEPIDOPTERA	GEOMETRIDAE	NEPYTIA	FREEMANI	5 12
LEPIDOPTERA	GEOMETRIDAE	NEPYTIA	PHANTASMARIA	12
LEPIDOPTERA	GEOMETRIDAE	NYCTOBIA	LIMITARIA NIGROANGULATA	12
LEPIDOPTERA	GEOMETRIDAE	NYCTOBIA	SP.	16
LEPIDOPTERA	GEOMETRIDAE	OENOCHROMA	VINARIA	13
LEPIDOPTERA	GEOMETRIDAE	OPEROPHTERA	BRUCEATA	5 12
LEPIDOPTERA	GEOMETRIDAE	OPEROPHTERA	BRUMATA	5 12 16 17 19
LEPIDOPTERA	GEOMETRIDAE	OPEROPHTERA	FAGATA	5
LEPIDOPTERA	GEOMETRIDAE	OPISTHOGRAPTIS	LUTEOLATA	12
LEPIDOPTERA	GEOMETRIDAE	OPORINIA	AUTUMNATA	5 12
LEPIDOPTERA	GEOMETRIDAE	OURAPTERYX	SAMBUCARIA	5
LEPIDOPTERA	GEOMETRIDAE	PALEACRITA	VERNATA	5 12
LEPIDOPTERA	GEOMETRIDAE	PERIBATODES	SIMPLICIARIA	12
LEPIDOPTERA	GEOMETRIDAE	PERO	BEHRENSARIUS	12
LEPIDOPTERA	GEOMETRIDAE	PERO	MIZON	12



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	GEOMETRIDAE	PHALAENA	VERNATA	(SEE PALEACRITA VERNATA)
LEPIDOPTERA	GEOMETRIDAE	PHIGALIA	PEDARIA	(SEE APOCHEIMA PILOSARIA)
LEPIDOPTERA	GEOMETRIDAE	PHIGALIA	TITEA	12
LEPIDOPTERA	GEOMETRIDAE	PHTHONOSEMA	TENDINOSARIA	12
LEPIDOPTERA	GEOMETRIDAE	PROTOBOARMIA	PORCELARIA INDICATARIA	12
LEPIDOPTERA	GEOMETRIDAE	PTYCHPODA	SERIATA	12 16
LEPIDOPTERA	GEOMETRIDAE	RHEUMAPTERA	HASTATA	9
LEPIDOPTERA	GEOMETRIDAE	SABULODES	CABERATA	9 16
LEPIDOPTERA	GEOMETRIDAE	SCOPULA	SP.	10
LEPIDOPTERA	GEOMETRIDAE	SCOPULA	SUBPUNCTARIA	12
LEPIDOPTERA	GEOMETRIDAE	SELENIA	LUNARIA	5
LEPIDOPTERA	GEOMETRIDAE	SELIDOSEMA	SUAVIS	5 12
LEPIDOPTERA	GEOMETRIDAE	SEMIOTHISA	LITURATA	5
LEPIDOPTERA	GEOMETRIDAE	SEMIOTHISA	PUMILA	13
LEPIDOPTERA	GEOMETRIDAE	SEMIOTHISA	SEXMACULATA	9
LEPIDOPTERA	GEOMETRIDAE	STERRHA	SERIATA	(SEE PTYCHPODA SERIATA)
LEPIDOPTERA	GEOMETRIDAE	SYNAXIS	JUBARARIA	12
LEPIDOPTERA	GEOMETRIDAE	SYNAXIS	PALLULATA	12
LEPIDOPTERA	GEOMETRIDAE	THERA	JUNIPERATA	5
LEPIDOPTERA	GRACILLARIIDAE	PARCTOPA	GEOMETROPIS	10
LEPIDOPTERA	HELICONIIDAE	MECHANITIS	VERITABILIS	17
LEPIDOPTERA	HEPIALIDAE	HEPIALUS	LUPULINUS	5
LEPIDOPTERA	HEPIALIDAE	METAHEPIALUS	XENOCTENIS	13
LEPIDOPTERA	HEPIALIDAE	ONCOPERA	ALBOGUTTATA	19
LEPIDOPTERA	HEPIALIDAE	PORINA	SP.	(SEE WISEANA SPP.)
LEPIDOPTERA	HEPIALIDAE	WISEANA	CERVINATA	9 10 12 19
LEPIDOPTERA	HEPIALIDAE	WISEANA	SIGNATA	12 19
LEPIDOPTERA	HEPIALIDAE	WISEANA	UMBRACULATA	9 12 19
LEPIDOPTERA	HESPERIIDAE	EPARGYREUS	CLARUS	12
LEPIDOPTERA	HESPERIIDAE	PARNARA	GUTTATA	10 12
LEPIDOPTERA	HESPERIIDAE	PARNARA	MATHIAS	12
LEPIDOPTERA	HESPERIIDAE	PELOPIDA	MATHIAS	(SEE PARNARA MATHIAS)
LEPIDOPTERA	HESPERIIDAE	POTANTHUS	CONFUCIUS FLAVA	(SEE POTANTHUS FLAVUM)
LEPIDOPTERA	HESPERIIDAE	POTANTHUS	FLAVUM	10
LEPIDOPTERA	HESPERIIDAE	THYMELICUS	LINEOLA	12
LEPIDOPTERA	HESPERIIDAE	URBANUS	PROTEUS	12
LEPIDOPTERA	LASIOCAMPIDAE	BHIMA	UNDULOSA	12
LEPIDOPTERA	LASIOCAMPIDAE	COSMOTRICHE	POTATORIA	12
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGMA	UNDANS	5 12
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGMA	UNDANS FASCIATELLA	12
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGMA	UNDANS FLAVEOLA	12
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGMA	YAMADAI	5 12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	LATIPENNIS	12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	PINI	5 12 16
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	PUNCTATUS	5 12 13
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	PUNCTATUS TEHCHANGENSIS	12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	SIBIRICUS	9
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	SPECTABILIS	5 9 12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	SUPERANS	5
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	TABULAEFORMIS	5
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	UNDANS	(SEE CYCLOPHRAGMA UNDANS)
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	UNDANS FLAVEOLA	(SEE CYCLOPHRAGMA UNDANS FLAVEOLA)
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	YAMADAI	(SEE CYCLOPHRAGMA YAMADAI)
LEPIDOPTERA	LASIOCAMPIDAE	ENTOMETA	APICALIS	13
LEPIDOPTERA	LASIOCAMPIDAE	ERIOGASTER	LANESTRIS	5
LEPIDOPTERA	LASIOCAMPIDAE	GASTROPACHA	QUERCIFOLIA	5 12
LEPIDOPTERA	LASIOCAMPIDAE	GASTROPACHA	QUERCIFOLIA CERRIDIFOLIA	5 10 12
LEPIDOPTERA	LASIOCAMPIDAE	GONOMETA	PODOCARPI	13
LEPIDOPTERA	LASIOCAMPIDAE	GONOMETA	RUFIBRUNNEA	5
LEPIDOPTERA	LASIOCAMPIDAE	KUNUGIA	YAMADAI	(SEE CYCLOPHRAGMA YAMADAI)
LEPIDOPTERA	LASIOCAMPIDAE	LASIOCAMPA	QUERCUS	5 12
LEPIDOPTERA	LASIOCAMPIDAE	LASIOCAMPA	TRIFOLII	12
LEPIDOPTERA	LASIOCAMPIDAE	LEBEDA	NOBILIS	12
LEPIDOPTERA	LASIOCAMPIDAE	LECHRIOLEPIS	BASIRUFA	12
LEPIDOPTERA	LASIOCAMPIDAE	MACROTHYLACIA	RUBI	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	ALPICOLA	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	AMERICANUM	5 12 13 16
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	CALIFORNICUM	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	CONSTRICUM	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	DISSTRIA	5 12 16
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	FRAGILE	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	FRAGILE INCURVA	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	LUTESCENS	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	NEUSTRIA	5 12 16
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	NEUSTRIA TESTACEA	5 12 16
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	PLUVIALE	9 12
LEPIDOPTERA	LASIOCAMPIDAE	METANASTRIA	UNDANS	(SEE CYCLOPHRAGMA UNDANS)
LEPIDOPTERA	LASIOCAMPIDAE	PACHYMETANA	SP.	13
LEPIDOPTERA	LASIOCAMPIDAE	PACHYPASA	CAPENSIS	12 13
LEPIDOPTERA	LASIOCAMPIDAE	PACHYPASA	OTUS	12
LEPIDOPTERA	LASIOCAMPIDAE	SELENEPHERA	LUNIGERA	12
LEPIDOPTERA	LASIOCAMPIDAE	TIGERA	CASTANEA	12
LEPIDOPTERA	LASIOCAMPIDAE	TRABALA	VISHNOU	12
LEPIDOPTERA	LIMACODIDAE	APODA	DENTATUS	10
LEPIDOPTERA	LIMACODIDAE	BARIA	ELSA	17
LEPIDOPTERA	LIMACODIDAE	CASPHALIA	EXTRANEA	6
LEPIDOPTERA	LIMACODIDAE	CNIDOCAMPA	FLAVESCENS	9 12
LEPIDOPTERA	LIMACODIDAE	DARNA	TRIMA	9 13
LEPIDOPTERA	LIMACODIDAE	DORATIFERA	CASTA	12
LEPIDOPTERA	LIMACODIDAE	EUPROSTERNA	ELEASA	17
LEPIDOPTERA	LIMACODIDAE	HYPHORNA	MINAX	12
LEPIDOPTERA	LIMACODIDAE	IRAGOIDES	FASCIATA	12
LEPIDOPTERA	LIMACODIDAE	LATOIA	CONSOCIA	(SEE PARASA CONSOCIA)
LEPIDOPTERA	LIMACODIDAE	LATOIA	LEPIDA	(SEE PARASA LEPIDA)
LEPIDOPTERA	LIMACODIDAE	LATOIA	VIRIDISSIMA	6
LEPIDOPTERA	LIMACODIDAE	MICROLEON	LONGIPALPIS	10
LEPIDOPTERA	LIMACODIDAE	NAROSA	CONSPERSA	17
LEPIDOPTERA	LIMACODIDAE	NATADA	NARARIA	9
LEPIDOPTERA	LIMACODIDAE	NATADA	SP.	17
LEPIDOPTERA	LIMACODIDAE	NIPHADOLEPIS	ALIANITA	17
LEPIDOPTERA	LIMACODIDAE	PARASA	BICOLOR	9
LEPIDOPTERA	LIMACODIDAE	PARASA	CONSOCIA	9 12
LEPIDOPTERA	LIMACODIDAE	PARASA	LEPIDA	9 12 17
LEPIDOPTERA	LIMACODIDAE	PARASA	SINICA	9 12
LEPIDOPTERA	LIMACODIDAE	SCOPELODES	CONTRACTA	5 12
LEPIDOPTERA	LIMACODIDAE	SCOPELODES	VENOSA	12
LEPIDOPTERA	LIMACODIDAE	SETORA	NITENS	13
LEPIDOPTERA	LIMACODIDAE	SETORA	POSTORNATA	5
LEPIDOPTERA	LIMACODIDAE	SIBINE	APICALIS	5
LEPIDOPTERA	LIMACODIDAE	SIBINE	FUSCA	6
LEPIDOPTERA	LIMACODIDAE	SIBINE	SP.	17
LEPIDOPTERA	LIMACODIDAE	SPATULIFIMBRIA	CASTANEICEPS	17
LEPIDOPTERA	LIMACODIDAE	SUSICA	NARARIA	(SEE NATADA NARARIA)
LEPIDOPTERA	LIMACODIDAE	THOSEA	ASIGNA	13
LEPIDOPTERA	LIMACODIDAE	THOSEA	BAIBARANA	12
LEPIDOPTERA	LIMACODIDAE	THOSEA	BISURA	17
LEPIDOPTERA	LIMACODIDAE	THOSEA	CANA	17
LEPIDOPTERA	LIMACODIDAE	THOSEA	CERVINA	17
LEPIDOPTERA	LIMACODIDAE	THOSEA	POSTORNATA	(SEE SETORA POSTORNATA)
LEPIDOPTERA	LIMACODIDAE	THOSEA	RECTA	17
LEPIDOPTERA	LIMACODIDAE	THOSEA	SINENSIS	9 12
LEPIDOPTERA	LYCAENIDAE	LYCAENA	PHLAEAS	5 10
LEPIDOPTERA	LYCAENIDAE	OGYRIS	ARBROTA	13
LEPIDOPTERA	LYMANTRIIDAE	ARCTORNIS	ALBA	12
LEPIDOPTERA	LYMANTRIIDAE	CIFUNA	LOCUPLES	(SEE DASYCHIRA LOCUPLES)
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	ABIETIS	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	ARGENTATA	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	AXUTHA	5 12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	BASIFLAVA	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	CONFUSA	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	GLAUCINOPTERA	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	LOCUPLES	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	MENDOSA	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	PLAGIATA	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	PSEUDABIETIS	10 12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	PUDIBUNDA	5 12 13 16
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	SELENITICA	16
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	BIPUNCTAPEX	12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	CHRYSORRHOEA	5 12 16
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	FLAVA	10 12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	FLAVINATA	12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	KARGHALICA	12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	PSEUDOCNOSPERSA	5 10 12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	SIMILIS	5 10 12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	SIMILIS XANTHOCAMPA	12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	SUBFLAVA	12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	TERMINALIS	16
LEPIDOPTERA	LYMANTRIIDAE	HEMEROCAMPA	PSEUDOTSUGATA	(SEE ORGYIA PSEUDOTSUGATA)
LEPIDOPTERA	LYMANTRIIDAE	IVELA	AURIPES	12
LEPIDOPTERA	LYMANTRIIDAE	IVELA	OCHROPODA	12
LEPIDOPTERA	LYMANTRIIDAE	LEUCOMA	CANDIDA	5 12
LEPIDOPTERA	LYMANTRIIDAE	LEUCOMA	SALICIS	5 12 16
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	DISPAR	5 6 10 12 13 15 16 17 19
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	DISPAR JAPONICA	5 12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	DISSOLUTA	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	FUMIDA FUMIDA	5 12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	INCERTA	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	MATHURA	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	MATHURA AURORA	5 12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	MONACHA	5 12 16
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	NINAYI	12 13
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	OBFUSCATA	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	VIOLASWINHOL	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	XYLINA	12
LEPIDOPTERA	LYMANTRIIDAE	NYGMIA	PHAEORRHOEA	16
LEPIDOPTERA	LYMANTRIIDAE	OCNERIA	DISPAR	(SEE LYMANTRIA DISPAR)
LEPIDOPTERA	LYMANTRIIDAE	OCNERIA	DISSOLUTA	(SEE LYMANTRIA DISSOLUTA)
LEPIDOPTERA	LYMANTRIIDAE	OCNERIA	MONACHA	(SEE LYMANTRIA MONACHA)
LEPIDOPTERA	LYMANTRIIDAE	OLENE	MENDOSA	(SEE DASYCHIRA MENDOSA)
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	ANARTOIDES	12 13
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	ANTIQUA	5 12 16
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	AUSTRALIS	12
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	BADIA	12
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	GONOSTIGMA	12
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	LEUCOSTIGMA	5 12 16 17
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	POSTICA	12
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	PSEUDOTSUGATA	5 12 16
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	TURBATA	12
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	VETUSTA	12
LEPIDOPTERA	LYMANTRIIDAE	PANTANA	PHYLLOSTACHYSAE	12
LEPIDOPTERA	LYMANTRIIDAE	PORTHESIA	SCINTILLANS	12
LEPIDOPTERA	LYMANTRIIDAE	PORTHESIA	SIMILIS	(SEE EUPROCTIS SIMILIS)
LEPIDOPTERA	LYMANTRIIDAE	PORTHESIA	XANTHOCAMPA	5
LEPIDOPTERA	LYMANTRIIDAE	PORTHETRIA	DISPAR	(SEE LYMANTRIA DISPAR)
LEPIDOPTERA	LYMANTRIIDAE	PORTHETRIA	DISPAR JAPONICA	(SEE LYMANTRIA DISPAR JAPONICA)
LEPIDOPTERA	LYMANTRIIDAE	PORTHETRIA	OBFUSCATA	(SEE LYMANTRIA OBFUSCATA)
LEPIDOPTERA	LYMANTRIIDAE	STILPNOTIA	SALICIS	(SEE LEUCOMA SALICIS)
LEPIDOPTERA	LYONETIIDAE	BUCCULATRIX	THURBERIELLA	12
LEPIDOPTERA	MEGALOPYGIDAE	MEGALOPYGE	OPERCULARIS	9
LEPIDOPTERA	NOCTUIDAE	ACHAEA	JANATA	9 12
LEPIDOPTERA	NOCTUIDAE	ACRONICTA	ACERIS	12
LEPIDOPTERA	NOCTUIDAE	ACTEBIA	FENNICA	12
LEPIDOPTERA	NOCTUIDAE	ADISURA	ATKINSONI	12
LEPIDOPTERA	NOCTUIDAE	ADRIS	TYRANNUS AMURENSIS	5
LEPIDOPTERA	NOCTUIDAE	AEDIA	LEUCOMELAS	12
LEPIDOPTERA	NOCTUIDAE	AGROCHOLA	HELVOLA	5
LEPIDOPTERA	NOCTUIDAE	AGROCHOLA	LYCHNIDIS	5



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	AGROTIS	EXCLAMATIONIS	9 12
LEPIDOPTERA	NOCTUIDAE	AGROTIS	FUCOSA	(SEE AGROTIS SEGETUM)
LEPIDOPTERA	NOCTUIDAE	AGROTIS	IPSILON	5 9 12
LEPIDOPTERA	NOCTUIDAE	AGROTIS	SEGETUM	5 9 12
LEPIDOPTERA	NOCTUIDAE	AGROTIS	SP.	17
LEPIDOPTERA	NOCTUIDAE	AGROTIS	TOKIONIS	9
LEPIDOPTERA	NOCTUIDAE	AGROTIS	YPSILON	(SEE AGROTIS IPSILON)
LEPIDOPTERA	NOCTUIDAE	ALABAMA	ARGILLACEA	12 16
LEPIDOPTERA	NOCTUIDAE	ALETIA	GXYGALA LUTEOPALLENS	12
LEPIDOPTERA	NOCTUIDAE	AMATHES	C-NIGRUM	5 9 12
LEPIDOPTERA	NOCTUIDAE	AMATHES	GLAREOSA	(SEE PARADIARSIA GLAREOSA)
LEPIDOPTERA	NOCTUIDAE	ANADEVIDIA	PEPONIS	10 12
LEPIDOPTERA	NOCTUIDAE	ANAGRAPHA	FALCIFERA	12
LEPIDOPTERA	NOCTUIDAE	ANCHOSCELIS	HELVOLA	(SEE AGROCHOLA HELVOLA)
LEPIDOPTERA	NOCTUIDAE	ANOMIS	FLAVA	12
LEPIDOPTERA	NOCTUIDAE	ANOMIS	SABULIFERA	12
LEPIDOPTERA	NOCTUIDAE	ANOMOGYNA	ELIMATA	12
LEPIDOPTERA	NOCTUIDAE	ANTICARSIA	GEMMATALIS	12 16
LEPIDOPTERA	NOCTUIDAE	ANTITYPE	XANTHOMISTA	5
LEPIDOPTERA	NOCTUIDAE	APAMEA	ANCEPS	9 12
LEPIDOPTERA	NOCTUIDAE	APAMEA	SORDENS	9
LEPIDOPTERA	NOCTUIDAE	APATELE	MAJOR	10
LEPIDOPTERA	NOCTUIDAE	APOROPHYLA	LUTULENTA	5
LEPIDOPTERA	NOCTUIDAE	APOROPHYLLA	LUTULENTA	(SEE APOROPHYLA LUTULENTA)
LEPIDOPTERA	NOCTUIDAE	ARCTE	COERULEA	5 10
LEPIDOPTERA	NOCTUIDAE	ARGYROGRAMMA	AGNATA	(SEE PLUSIA AGNATA)
LEPIDOPTERA	NOCTUIDAE	ARGYROGRAMMA	BASIGERA	12
LEPIDOPTERA	NOCTUIDAE	ATHETIS	ALBINA	9
LEPIDOPTERA	NOCTUIDAE	ATHETIS	AMBIGUA	(SEE HOPLODRINA AMBIGUA)
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	BILOBA	12 16
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	BIMACULATA	12
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	BRASSICAE	(SEE TRICHOPLUSIA NI)
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	CALIFORNICA	5 9 12 13
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	GAMMA	5 12
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	NIGRISIGNA	12
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	PRECAUTIONIS	12
LEPIDOPTERA	NOCTUIDAE	AXYLIA	PUTRIS	5
LEPIDOPTERA	NOCTUIDAE	BARATHRA	BRASSICAE	(SEE MAMESTRA BRASSICAE)
LEPIDOPTERA	NOCTUIDAE	BELLURA	GORTYNOIDES	12
LEPIDOPTERA	NOCTUIDAE	BELLURA	VULNIFICA	(SEE BELLURA GORTYNOIDES)
LEPIDOPTERA	NOCTUIDAE	BLEPHARITA	SOLIERI	5
LEPIDOPTERA	NOCTUIDAE	CALOPHASIA	LUNULA	5 12
LEPIDOPTERA	NOCTUIDAE	CATABENA	ESULA	12 16
LEPIDOPTERA	NOCTUIDAE	CATOCALA	CONJUNCTA	12
LEPIDOPTERA	NOCTUIDAE	CATOCALA	NYMPHAEA	12
LEPIDOPTERA	NOCTUIDAE	CATOCALA	NYMPHAGOGA	12
LEPIDOPTERA	NOCTUIDAE	CERAMICA	PICTA	5 12
LEPIDOPTERA	NOCTUIDAE	CERAMICA	PISI	12
LEPIDOPTERA	NOCTUIDAE	CERAPTERYX	GRAMINIS	12 16
LEPIDOPTERA	NOCTUIDAE	CHARAEAS	GRAMINIS	(SEE CERAPTERYX GRAMINIS)
LEPIDOPTERA	NOCTUIDAE	CHLORIDEA	OBSOLETA	(SEE HELIOTHIS ARMIGERA)
LEPIDOPTERA	NOCTUIDAE	CHORIZAGROTIS	AUXILIARIS	(SEE EUXOA AUXILIARIS)
LEPIDOPTERA	NOCTUIDAE	CHRYSEIDEXIS	CHALCITES	12
LEPIDOPTERA	NOCTUIDAE	CHRYSEIDEXIS	ERIOSOMA	5 12 13
LEPIDOPTERA	NOCTUIDAE	COSMOPHILA	FLAVA	(SEE ANOMIS FLAVA)
LEPIDOPTERA	NOCTUIDAE	CRINO	SOLIERI	(SEE BLEPHARITA SOLIERI)
LEPIDOPTERA	NOCTUIDAE	CRYMIDES	DEVASTATOR	5
LEPIDOPTERA	NOCTUIDAE	DIACHRYSLA	ORICHALCEA	12
LEPIDOPTERA	NOCTUIDAE	DIARSIA	CANESCENS	10
LEPIDOPTERA	NOCTUIDAE	DIATARAXIA	OLERACEA	(SEE LACANOBIA OLERACEA)
LEPIDOPTERA	NOCTUIDAE	DICYCLA	OO	12
LEPIDOPTERA	NOCTUIDAE	DIPAROPSIS	WATERSI	5 12
LEPIDOPTERA	NOCTUIDAE	DISCESTRA	TRIFOLII	(SEE SCOTOGRAMMA TRIFOLII)
LEPIDOPTERA	NOCTUIDAE	DRYOBOTA	FURVA	9 12
LEPIDOPTERA	NOCTUIDAE	DRYOBOTA	PROTEA	12
LEPIDOPTERA	NOCTUIDAE	DRYOBOTODES	MONOCHROMA	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	EARIAS	BIPLAGA	5
LEPIDOPTERA	NOCTUIDAE	EARIAS	INSULANA	5 12 17
LEPIDOPTERA	NOCTUIDAE	ELYGMA	NARCISSUS	10
LEPIDOPTERA	NOCTUIDAE	EUPLEXIA	LUCIPARA	9
LEPIDOPTERA	NOCTUIDAE	EUPSILIA	SATELLITIA	9
LEPIDOPTERA	NOCTUIDAE	EUPSILIA	SP.	12
LEPIDOPTERA	NOCTUIDAE	EUXOA	AUXILIARIS	9 12 13 16 19
LEPIDOPTERA	NOCTUIDAE	EUXOA	MESSORIA	5 9 12
LEPIDOPTERA	NOCTUIDAE	EUXOA	OCHROGASTER	5 9 12 16
LEPIDOPTERA	NOCTUIDAE	EUXOA	SCANDENS	5 12
LEPIDOPTERA	NOCTUIDAE	FELTIA	SUBTERRANEA	9
LEPIDOPTERA	NOCTUIDAE	FERALIA	JACOSA	12
LEPIDOPTERA	NOCTUIDAE	HADA	NANA	5
LEPIDOPTERA	NOCTUIDAE	HADENA	BASILINEA	9
LEPIDOPTERA	NOCTUIDAE	HADENA	SERENA	5
LEPIDOPTERA	NOCTUIDAE	HADENA	SORDIDA	9 12
LEPIDOPTERA	NOCTUIDAE	HELIOPHOBUS	ALBICOLON	5
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	ARMIGERA	5 9 10 12 13
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	ASSULTA	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	OBTECTUS	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PARADOXA	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PELTIGERA	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PHLOXIPHAGA	12 16
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PUNCTIGERA	9 12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	RUBRESCENS	9
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	SUBFLEXA	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	VIRESCENS	5 12 13 16
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	ZEIA	5 9 10 12 13
LEPIDOPTERA	NOCTUIDAE	HOPLODRINA	AMBIGUA	12
LEPIDOPTERA	NOCTUIDAE	HYDRILLODES	MOROSA	10
LEPIDOPTERA	NOCTUIDAE	LACANOBIA	OLERACEA	5 9 12
LEPIDOPTERA	NOCTUIDAE	LAMPRA	FIMBRIATA	5
LEPIDOPTERA	NOCTUIDAE	LAPHYGMA	EXIGUA	(SEE SPODOPTERA EXIGUA)
LEPIDOPTERA	NOCTUIDAE	LAPHYGMA	FRUGIPERDA	(SEE SPODOPTERA FRUGIPERDA)
LEPIDOPTERA	NOCTUIDAE	LEUCANIA	SEPARATA	(SEE PSEUDALETIA SEPARATA)
LEPIDOPTERA	NOCTUIDAE	LITHOPHANE	LEAUTIERI	5
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	BRASSICAE	5 6 9 10 12 13
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	CONFIGURATA	9 12
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	OLERACEA	(SEE LACANOBIA OLERACEA)
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	PISI	(SEE CERAMICA PISI)
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	SP.	9
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	SUASA	12
LEPIDOPTERA	NOCTUIDAE	MANIA	MAURA	5
LEPIDOPTERA	NOCTUIDAE	MELANCHRA	PERSICARIAE	9
LEPIDOPTERA	NOCTUIDAE	MOCIS	UNDATA	5
LEPIDOPTERA	NOCTUIDAE	MOMA	CHAMPA	12
LEPIDOPTERA	NOCTUIDAE	MYTHIMNA	SEPARATA	(SEE PSEUDALETIA SEPARATA)
LEPIDOPTERA	NOCTUIDAE	MYTHIMNA	UNIPUNCTA	(SEE PSEUDALETIA UNIPUNCTA)
LEPIDOPTERA	NOCTUIDAE	NEPHELODES	EMMEDONIA	9 12 16
LEPIDOPTERA	NOCTUIDAE	NOCTUA	PRONUBA	5 12
LEPIDOPTERA	NOCTUIDAE	OPHIUSA	CORONATA	17
LEPIDOPTERA	NOCTUIDAE	ORAESIA	EMARGINATA	5 12
LEPIDOPTERA	NOCTUIDAE	ORAESIA	EXCAVATA	5
LEPIDOPTERA	NOCTUIDAE	ORTHOSIA	HIBISCI	12
LEPIDOPTERA	NOCTUIDAE	ORTHOSIA	INCERTA	12
LEPIDOPTERA	NOCTUIDAE	PANOLIS	FLAMMEA	12 16
LEPIDOPTERA	NOCTUIDAE	PANTHEA	PORTLANDIA	12
LEPIDOPTERA	NOCTUIDAE	PAPAPEMA	PURPURIFASCIA	9
LEPIDOPTERA	NOCTUIDAE	PARADIARSIA	GLAREOSA	5
LEPIDOPTERA	NOCTUIDAE	PERIDROMA	MARGARITOSA	(SEE PERIDROMA SAUCIA)
LEPIDOPTERA	NOCTUIDAE	PERIDROMA	SAUCIA	5 9 12 16
LEPIDOPTERA	NOCTUIDAE	PERIDROMA	SP.	9 12
LEPIDOPTERA	NOCTUIDAE	PERSECTANIA	EWINGII	9 13 15
LEPIDOPTERA	NOCTUIDAE	PHLOGOPHORA	METICULOSA	5 12
LEPIDOPTERA	NOCTUIDAE	PLATHYPENA	SCABRA	9 12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	AGNATA	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	PLUSIA	AGRAMMA	(SEE ANAEVIDIA PEONIS)
LEPIDOPTERA	NOCTUIDAE	PLUSIA	ARGENTIFERA	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	BALLUCA	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	BRASSICAE	(SEE TRICHOPLUSIA NI)
LEPIDOPTERA	NOCTUIDAE	PLUSIA	CHALCYTES	(SEE CHRYSODEIXIS CHALCITES)
LEPIDOPTERA	NOCTUIDAE	PLUSIA	CIRCUMFLEXA	9
LEPIDOPTERA	NOCTUIDAE	PLUSIA	GAMMA	(SEE AUTOGRAPHIA GAMMA)
LEPIDOPTERA	NOCTUIDAE	PLUSIA	ORICHALCEA	(SEE DIACHRYSLA ORICHALCEA)
LEPIDOPTERA	NOCTUIDAE	PLUSIA	PEONIS	(SEE ANAEVIDIA PEONIS)
LEPIDOPTERA	NOCTUIDAE	PLUSIA	SIGNATA	12
LEPIDOPTERA	NOCTUIDAE	PODIOPLUSIA	PEONIS	(SEE ANAEVIDIA PEONIS)
LEPIDOPTERA	NOCTUIDAE	PRODENIA	ANDROGEA	9
LEPIDOPTERA	NOCTUIDAE	PRODENIA	LITOSIA	12
LEPIDOPTERA	NOCTUIDAE	PRODENIA	LITURA	(SEE SPODOPTERA LITURA)
LEPIDOPTERA	NOCTUIDAE	PRODENIA	ORNITHOGALLI	(SEE SPODOPTERA ORNITHOGALLI)
LEPIDOPTERA	NOCTUIDAE	PRODENIA	PRAEFICA	12
LEPIDOPTERA	NOCTUIDAE	PRODENIA	TERRICOLA	12
LEPIDOPTERA	NOCTUIDAE	PSEUDALETIA	CONVECTA	9 12
LEPIDOPTERA	NOCTUIDAE	PSEUDALETIA	SEPARATA	9 12 13 19
LEPIDOPTERA	NOCTUIDAE	PSEUDALETIA	UNIPUNCTA	5 9 10 12 13 16
LEPIDOPTERA	NOCTUIDAE	PSEUDOPUSIA	INCLUDENS	6 12 13 17
LEPIDOPTERA	NOCTUIDAE	RACIPLUSIA	NU	12 16
LEPIDOPTERA	NOCTUIDAE	RACIPLUSIA	OU	12
LEPIDOPTERA	NOCTUIDAE	SCOLIOPTERYX	LIBATRIX	5 12
LEPIDOPTERA	NOCTUIDAE	SCOTIA	SEGETUM	(SEE AGROTIS SEGETUM)
LEPIDOPTERA	NOCTUIDAE	SCOTOGRAMMA	TRIFOLII	5 9 12
LEPIDOPTERA	NOCTUIDAE	SELEPA	CELTIS	9
LEPIDOPTERA	NOCTUIDAE	SESAMIA	CALAMISTIS	5 12 13
LEPIDOPTERA	NOCTUIDAE	SESAMIA	CRETICA	9
LEPIDOPTERA	NOCTUIDAE	SESAMIA	INFERENS	12
LEPIDOPTERA	NOCTUIDAE	SESAMIA	NONAGRIODES	9
LEPIDOPTERA	NOCTUIDAE	SPAELOTIS	CLANDESTINA	16
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	EXEMPTA	5 12 17
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	EXIGUA	5 9 12
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	FRUGIPERDA	5 9 10 11 12 13 16
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	LATIFASCIA	12
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	LITTORALIS	9 12 17
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	LITURA	5 9 10 12 16
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	MAURITIA	12 16
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	MAURITIA ACRONYCTOIDES	12
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	ORNITHOGALLI	12 16
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	SP.	12
LEPIDOPTERA	NOCTUIDAE	SYNGRAPHIA	SELECTA	12
LEPIDOPTERA	NOCTUIDAE	TIRACOLA	PLAGIATA	12
LEPIDOPTERA	NOCTUIDAE	TRICHOPLUSIA	NI	5 9 10 12 13
LEPIDOPTERA	NOCTUIDAE	TRICHOSEA	CHAMPA	(SEE MOMA CHAMPA)
LEPIDOPTERA	NOCTUIDAE	TRIPHAENA	PRONUBA	(SEE NOCTUA PRONUBA)
LEPIDOPTERA	NOCTUIDAE	XESTIA	C-NIGRUM	(SEE AMATHES C-NIGRUM)
LEPIDOPTERA	NOCTUIDAE	XYLENA	CURVIMACULA	12
LEPIDOPTERA	NOCTUIDAE	XYLOMYGES	CONSPICILLARIS	5
LEPIDOPTERA	NOTODONTIDAE	CERURA	BIFIDA	(SEE CERURA HERMELINA)
LEPIDOPTERA	NOTODONTIDAE	CERURA	HERMELINA	12 16
LEPIDOPTERA	NOTODONTIDAE	CERURA	VINULA	5
LEPIDOPTERA	NOTODONTIDAE	CLOSTERA	ANACHORETA	(SEE PYGAERA ANACHORETA)
LEPIDOPTERA	NOTODONTIDAE	CLOSTERA	ANASTOMOSIS	(SEE PYGAERA ANASTOMOSIS)
LEPIDOPTERA	NOTODONTIDAE	HETEROCAMPA	GUTTIVITTA	16
LEPIDOPTERA	NOTODONTIDAE	LEPTONATADA	SJOSTEDTI	17
LEPIDOPTERA	NOTODONTIDAE	LEUCODONTA	BICOLORIA	13
LEPIDOPTERA	NOTODONTIDAE	LOPHOPTERYX	CAMELINA	12
LEPIDOPTERA	NOTODONTIDAE	LOPHOPTERYX	CAPUCINA	5
LEPIDOPTERA	NOTODONTIDAE	MELALOPHA	ANASTOMOSIS	(SEE PYGAERA ANASTOMOSIS)
LEPIDOPTERA	NOTODONTIDAE	NADATA	GIBBOSA	12
LEPIDOPTERA	NOTODONTIDAE	NEOPHEOSIA	EXCURVATA	12
LEPIDOPTERA	NOTODONTIDAE	PHALERA	ASSIMILIS	12
LEPIDOPTERA	NOTODONTIDAE	PHALERA	BUCEPHALA	5 12
LEPIDOPTERA	NOTODONTIDAE	PHALERA	FLAVESCENS	12



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANACHORETA	9 10
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANASTOMOSIS	5 9 12 17
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANASTOMOSIS ORIENTALIS	5 12
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANASTOMOSIS TRISTIS	5 12
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	FULGURITA	12
LEPIDOPTERA	NOTODONTIDAE	SCHIZURA	CONCINNA	5
LEPIDOPTERA	NOTODONTIDAE	SEMIDONTA	BILOBA	12
LEPIDOPTERA	NOTODONTIDAE	STAUROPUS	ALTERNUS	16
LEPIDOPTERA	NYMPHALIDAE	AGLAIS	URTICAE	5 6 12 16
LEPIDOPTERA	NYMPHALIDAE	AGRAULIS	VANILLAE	6 12 13
LEPIDOPTERA	NYMPHALIDAE	ARASCHNIA	LEVANA	12
LEPIDOPTERA	NYMPHALIDAE	ARGYNNIS	DIA	(SEE BOLORIA DIA)
LEPIDOPTERA	NYMPHALIDAE	ARGYNNIS	LATHONIA	16
LEPIDOPTERA	NYMPHALIDAE	ARGYNNIS	PAPHIA	12 16
LEPIDOPTERA	NYMPHALIDAE	ARGYREUS	HYPERBIUS	10
LEPIDOPTERA	NYMPHALIDAE	ASTEROCAMPA	CELTIS	12
LEPIDOPTERA	NYMPHALIDAE	BOLORIA	DIA	5
LEPIDOPTERA	NYMPHALIDAE	CHARAXES	JASIUS	16
LEPIDOPTERA	NYMPHALIDAE	CLOSSIANA	DIA	(SEE BOLORIA DIA)
LEPIDOPTERA	NYMPHALIDAE	HESTINA	JAPONICA	10
LEPIDOPTERA	NYMPHALIDAE	INACHIS	IO	5 10 12 16
LEPIDOPTERA	NYMPHALIDAE	JUNONIA	COENIA	6 9 12 16
LEPIDOPTERA	NYMPHALIDAE	MELITAEA	DIDYMA	12
LEPIDOPTERA	NYMPHALIDAE	NYMPHALIS	ANTIOPA	5 9 12 16
LEPIDOPTERA	NYMPHALIDAE	NYMPHALIS	IO	(SEE INACHIS IO)
LEPIDOPTERA	NYMPHALIDAE	NYMPHALIS	POLYCHLOROS	12 16
LEPIDOPTERA	NYMPHALIDAE	POLYGONIA	C-ALBUM	5 12
LEPIDOPTERA	NYMPHALIDAE	POLYGONIA	SATYRUS	12
LEPIDOPTERA	NYMPHALIDAE	PYRAMEIS	ATALANTA	(SEE VANESSA ATALANTA)
LEPIDOPTERA	NYMPHALIDAE	PYRAMEIS	CARDUI	(SEE VANESSA CARDUI)
LEPIDOPTERA	NYMPHALIDAE	VANESSA	ATALANTA	12 16
LEPIDOPTERA	NYMPHALIDAE	VANESSA	CARDUI	5 10 12 16
LEPIDOPTERA	NYMPHALIDAE	VANESSA	IO	(SEE INACHIS IO)
LEPIDOPTERA	NYMPHALIDAE	VANESSA	POLYCHLOROS	(SEE NYMPHALIS POLYCHLOROS)
LEPIDOPTERA	NYMPHALIDAE	VANESSA	PRORSA	12
LEPIDOPTERA	NYMPHALIDAE	VANESSA	TAMMEAMEA	16
LEPIDOPTERA	NYMPHALIDAE	VANESSA	URTICAE	(SEE AGLAIS URTICAE)
LEPIDOPTERA	OECOPHORIDAE	CHIMBACE	FAGELLA	(SEE DIURNEA FAGELLA)
LEPIDOPTERA	OECOPHORIDAE	DIURNEA	FAGELLA	16
LEPIDOPTERA	PAPILIONIDAE	GRAPHIUM	SARPEDON	10
LEPIDOPTERA	PAPILIONIDAE	LUEHDORFIA	JAPONICA	12
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	ANACTUS	13
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	DAUNIS	12
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	DEMOLEUS	12
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	MACHAON	5
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	MACHAON HIPPOCRATES	10
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	PODALIRIUS	12
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	POLYXENES	12
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	XUTHUS	12
LEPIDOPTERA	PIERIDAE	APORIA	CRATAEGI	5 12 16
LEPIDOPTERA	PIERIDAE	ARTOGEIA	RAPAE	(SEE PIERIS RAPAE)
LEPIDOPTERA	PIERIDAE	ARTOGEIA	VIRGINIENSIS	(SEE PIERIS VIRGINIENSIS)
LEPIDOPTERA	PIERIDAE	CATOPSILIA	POMONA	6 12
LEPIDOPTERA	PIERIDAE	COLIAS	CHRYSOTHEME CHRYSOTHEME	16
LEPIDOPTERA	PIERIDAE	COLIAS	ELECTO	12 16
LEPIDOPTERA	PIERIDAE	COLIAS	EURYTHEME	5 12
LEPIDOPTERA	PIERIDAE	COLIAS	LESBIA	12
LEPIDOPTERA	PIERIDAE	COLIAS	PHILODICE	12 16
LEPIDOPTERA	PIERIDAE	EUCHLOE	CARDAMINES	5
LEPIDOPTERA	PIERIDAE	GONEPTERYX	RHAMNI	5
LEPIDOPTERA	PIERIDAE	NEOPHASIA	MENAPIA	12
LEPIDOPTERA	PIERIDAE	PIERIS	BRASSICAE	5 9 10 13 17
LEPIDOPTERA	PIERIDAE	PIERIS	BRASSICAE CHEIRANTHI	9
LEPIDOPTERA	PIERIDAE	PIERIS	MELETE	10
LEPIDOPTERA	PIERIDAE	PIERIS	NAPI	9
LEPIDOPTERA	PIERIDAE	PIERIS	RAPAE	5 6 9 12 13 16

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	PIERIDAE	PIERIS	RAPAE CRUCIVORA	5 9 12
LEPIDOPTERA	PIERIDAE	PIERIS	VIRGINIENSIS	9
LEPIDOPTERA	PIERIDAE	PONTIA	DAPLIDICE	9
LEPIDOPTERA	PLUTELLIDAE	PLUTELLA	MACULIPENNIS	(SEE PLUTELLA XYLOSTELLA)
LEPIDOPTERA	PLUTELLIDAE	PLUTELLA	XYLOSTELLA	9 10 12 13
LEPIDOPTERA	PSYCHIDAE	ACANTHOPSYCHE	JUNODI	(SEE CRYPTOTHELEA JUNODI)
LEPIDOPTERA	PSYCHIDAE	CANEPHORA	ASIATICA	12
LEPIDOPTERA	PSYCHIDAE	CLANIA	IGNOBILIS	13
LEPIDOPTERA	PSYCHIDAE	CRYPTOTHELEA	JAPONICA	(SEE CRYPTOTHELEA VARIEGATA)
LEPIDOPTERA	PSYCHIDAE	CRYPTOTHELEA	JUNODI	12
LEPIDOPTERA	PSYCHIDAE	CRYPTOTHELEA	VARIEGATA	12
LEPIDOPTERA	PSYCHIDAE	EUMETA	VARIEGATA	(SEE CRYPTOTHELEA VARIEGATA)
LEPIDOPTERA	PSYCHIDAE	KOTOCHALIA	JUNODI	(SEE CRYPTOTHELEA JUNODI)
LEPIDOPTERA	PSYCHIDAE	MAHASENA	CORBETTI	17
LEPIDOPTERA	PSYCHIDAE	MAHASENA	MINUSCULA	12
LEPIDOPTERA	PSYCHIDAE	OIKETYCUS	KIRBYI	5
LEPIDOPTERA	PSYCHIDAE	OREOPSYCHE	ANGUSTELLA	19
LEPIDOPTERA	PSYCHIDAE	THYRIDOPTERYX	EPHEMERAIFORMIS	12 17
LEPIDOPTERA	PYRALIDAE	ACHROEA	GRISELLA	(SEE ACHROIA GRISELLA)
LEPIDOPTERA	PYRALIDAE	ACHROIA	GRISELLA	12
LEPIDOPTERA	PYRALIDAE	ACROBASIS	ZELLERI	19
LEPIDOPTERA	PYRALIDAE	ALGEDONIA	COCLESALIS	10
LEPIDOPTERA	PYRALIDAE	AMYELOIS	TRANSITELLA	12 13 17
LEPIDOPTERA	PYRALIDAE	ANAGASTA	KUEHNIELLA	12
LEPIDOPTERA	PYRALIDAE	BLEPHAROMASTIX	ACUTANGULALIS	16
LEPIDOPTERA	PYRALIDAE	BOTYODES	DINIASALIS	(SEE PYRAUSTA DINIASALIS)
LEPIDOPTERA	PYRALIDAE	CACTOBLASTIS	CACTORUM	5
LEPIDOPTERA	PYRALIDAE	CADRA	CAUTELLA	5 9 12
LEPIDOPTERA	PYRALIDAE	CADRA	FIGULILELLA	9 12
LEPIDOPTERA	PYRALIDAE	CHILO	INFUSCATELLUS	9
LEPIDOPTERA	PYRALIDAE	CHILO	SACCHARIPHAGUS	5
LEPIDOPTERA	PYRALIDAE	CHILO	SACCHARIPHAGUS INDICUS	9
LEPIDOPTERA	PYRALIDAE	CHILO	SUPPRESSALIS	9 10 12
LEPIDOPTERA	PYRALIDAE	CNAPHALOCROCIS	MEDINALIS	9 10
LEPIDOPTERA	PYRALIDAE	CORCYRA	CEPHALONICA	12
LEPIDOPTERA	PYRALIDAE	CRYPTOBLABES	LARICIANA	12
LEPIDOPTERA	PYRALIDAE	DIAPHANIA	INDICA	(SEE MARGARONIA INDICA)
LEPIDOPTERA	PYRALIDAE	DIAPHANIA	PYLOALIS	(SEE MARGARONIA PYLOALIS)
LEPIDOPTERA	PYRALIDAE	DIATRAEA	GRANDIOSELLA	12
LEPIDOPTERA	PYRALIDAE	DIATRAEA	SACCHARALIS	6 9 12
LEPIDOPTERA	PYRALIDAE	DICHOCROCIS	PUNCTIFERALIS	12
LEPIDOPTERA	PYRALIDAE	DIORYCTRIA	ABIETELLA	9
LEPIDOPTERA	PYRALIDAE	DIORYCTRIA	PSEUDOTSUGELLA	12
LEPIDOPTERA	PYRALIDAE	DIORYCTRIA	SPLENIDELLA	17
LEPIDOPTERA	PYRALIDAE	ELASMOPALPUS	LIGNOSELLUS	19
LEPIDOPTERA	PYRALIDAE	EPHESTIA	CAUTELLA	(SEE CADRA CAUTELLA)
LEPIDOPTERA	PYRALIDAE	EPHESTIA	ELUTELLA	12
LEPIDOPTERA	PYRALIDAE	EPHESTIA	KUEHNIELLA	(SEE ANAGASTA KUEHNIELLA)
LEPIDOPTERA	PYRALIDAE	GALLERIA	MELLONELLA	5 6 10 12 13 15 16 17 19
LEPIDOPTERA	PYRALIDAE	GLYPHODES	PYLOALIS	(SEE MARGARONIA PYLOALIS)
LEPIDOPTERA	PYRALIDAE	LOXOSTEGE	STICTICALIS	9 12
LEPIDOPTERA	PYRALIDAE	MARGARONIA	INDICA	10
LEPIDOPTERA	PYRALIDAE	MARGARONIA	PYLOALIS	6 10
LEPIDOPTERA	PYRALIDAE	MARUCA	TESTULALIS	5
LEPIDOPTERA	PYRALIDAE	NACOLEIA	DIEMENALIS	9
LEPIDOPTERA	PYRALIDAE	NACOLEIA	OCTOSEMA	12
LEPIDOPTERA	PYRALIDAE	NAGIA	BALTEATA	10
LEPIDOPTERA	PYRALIDAE	NAGIA	INFERIOR	10
LEPIDOPTERA	PYRALIDAE	NOTARCHA	DEROGATA	10
LEPIDOPTERA	PYRALIDAE	NYMPHULA	DEPUNCTALIS	12
LEPIDOPTERA	PYRALIDAE	OMIODES	BLACKBURNI	17
LEPIDOPTERA	PYRALIDAE	OSTRINIA	NUBILALIS	12 17
LEPIDOPTERA	PYRALIDAE	PARAMYELOIS	TRANSITELLA	(SEE AMYELOIS TRANSITELLA)
LEPIDOPTERA	PYRALIDAE	PLODIA	INTERPUNCTELLA	9 12
LEPIDOPTERA	PYRALIDAE	PYRAUSTA	DINIASALIS	12
LEPIDOPTERA	PYRALIDAE	SCELIODES	CORDALIS	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	PYRALIDAE	SCIRPOPHAGA	INCERTULAS	12
LEPIDOPTERA	PYRALIDAE	SYBRIDA	MISAKIENSIS	10
LEPIDOPTERA	PYRALIDAE	TETRALOPHA	SCORTEALIS	12 16
LEPIDOPTERA	PYRALIDAE	WITLESIA	SABULOSELLA	10
LEPIDOPTERA	SATURNIIDAE	ACTIAS	LUNA	5
LEPIDOPTERA	SATURNIIDAE	ACTIAS	SELENE	5 13
LEPIDOPTERA	SATURNIIDAE	ACTIAS	SELENE NINGPOANA	12
LEPIDOPTERA	SATURNIIDAE	ANISOTA	SENATORIA	12 16
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	EUCALYPTI	5 10 13 15 17
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	HELENA	13
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	MYLITTA	(SEE ANTHRAEA PAPHIA MYLITTA)
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	PAPHIA MYLITTA	5 12
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	PERNYI	5 12 13 16
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	POLYPHEMUS	5 12 16
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	YAMAMAI	10 12 16
LEPIDOPTERA	SATURNIIDAE	AUTOMERIS	AURANTIACA	5
LEPIDOPTERA	SATURNIIDAE	AUTOMERIS	IO	5
LEPIDOPTERA	SATURNIIDAE	AUTOMERIS	MEMUSAE	5
LEPIDOPTERA	SATURNIIDAE	COLORADIA	PANDORA	12 16
LEPIDOPTERA	SATURNIIDAE	DICTYOPLOCA	JAPONICA	5 10 12
LEPIDOPTERA	SATURNIIDAE	DIRPHIA	GRAGATUS	12
LEPIDOPTERA	SATURNIIDAE	ERIOGYNA	PYRETORUM	12
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	EGLANTERINA	9 12 16
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	MAIA	12 16
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	OLIVIAE	9 12 16
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	SP.	12
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	TRICOLOR	12 16
LEPIDOPTERA	SATURNIIDAE	HYALOPHORA	CECROPIA	5 12 13
LEPIDOPTERA	SATURNIIDAE	HYLESIA	NIGRICANS	12
LEPIDOPTERA	SATURNIIDAE	HYLESIA	SP.	12
LEPIDOPTERA	SATURNIIDAE	NUDAURELIA	CYTHAREA CAPENSIS	(SEE N. CYTHAREA CYTHAREA)
LEPIDOPTERA	SATURNIIDAE	NUDAURELIA	CYTHAREA CLARKI	13
LEPIDOPTERA	SATURNIIDAE	NUDAURELIA	CYTHAREA CYTHAREA	5 13 16
LEPIDOPTERA	SATURNIIDAE	PHILOSAMIA	CYNTHIA	(SEE SAMIA CYNTHIA)
LEPIDOPTERA	SATURNIIDAE	PHILOSAMIA	CYNTHIA PRYERI	(SEE SAMIA PRYERI)
LEPIDOPTERA	SATURNIIDAE	PLATYSAMIA	CECROPIA	(SEE HYALOPHORA CECROPIA)
LEPIDOPTERA	SATURNIIDAE	PSEUDOBUNAEA	IRIUS	17
LEPIDOPTERA	SATURNIIDAE	PSEUDOHAZIS	EGLANTERINA	(SEE HEMILEUCA EGLANTERINA)
LEPIDOPTERA	SATURNIIDAE	SAMIA	CYNTHIA	5 12 13 16
LEPIDOPTERA	SATURNIIDAE	SAMIA	PRYERI	5 10 12
LEPIDOPTERA	SATURNIIDAE	SAMIA	RICINI	5 7 12 13 16
LEPIDOPTERA	SATURNIIDAE	SATURNIA	PAVONIA MAJOR	(SEE SATURNIA PYRI)
LEPIDOPTERA	SATURNIIDAE	SATURNIA	PYRI	5 12 13 16
LEPIDOPTERA	SATYRIDAE	DIRA	MEGERA	5
LEPIDOPTERA	SATYRIDAE	PARARGE	AEGERIA	5
LEPIDOPTERA	SCYTHRIDIDAE	SCYTHRIS	SINENSIS	10
LEPIDOPTERA	SESIIDAE	PARANTHRENE	PERNIX	10
LEPIDOPTERA	SPHINGIDAE	ACHERONTIA	ATROPUS	13
LEPIDOPTERA	SPHINGIDAE	AMPELOPHAGA	RUBIGINOSA	12
LEPIDOPTERA	SPHINGIDAE	CELERIO	EUPHORBIAE	(SEE HYLES EUPHORBIAE)
LEPIDOPTERA	SPHINGIDAE	CELERIO	GALLII	(SEE HYLES GALLII)
LEPIDOPTERA	SPHINGIDAE	CELERIO	HARMUTHI	16
LEPIDOPTERA	SPHINGIDAE	CELERIO	KINDERVATERI	16
LEPIDOPTERA	SPHINGIDAE	CELERIO	LINEATA	(SEE HYLES LINEATA)
LEPIDOPTERA	SPHINGIDAE	CELERIO	PHILEUPHORBIAE	16
LEPIDOPTERA	SPHINGIDAE	CELEKIO	VESPERTILIO	16
LEPIDOPTERA	SPHINGIDAE	CEPHONODES	HYLAS	10
LEPIDOPTERA	SPHINGIDAE	DEILEPHILA	ELPENOR	5 12 16
LEPIDOPTERA	SPHINGIDAE	DEILEPHILA	EUPHORBIAE	(SEE HYLES EUPHORBIAE)
LEPIDOPTERA	SPHINGIDAE	DILINA	TILIAE	5
LEPIDOPTERA	SPHINGIDAE	ERINNYIS	ELLO	12
LEPIDOPTERA	SPHINGIDAE	HERSE	CONVOLVULI	5
LEPIDOPTERA	SPHINGIDAE	HIPPOTON	ESON	12
LEPIDOPTERA	SPHINGIDAE	HYLES	EUPHORBIAE	5 12 16
LEPIDOPTERA	SPHINGIDAE	HYLES	GALLII	12 16
LEPIDOPTERA	SPHINGIDAE	HYLES	LINEATA	12



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	SPHINGIDAE	HYLOICUS	PINASTRI	5 12
LEPIDOPTERA	SPHINGIDAE	LAOTHOE	POPULI	5 12
LEPIDOPTERA	SPHINGIDAE	MACROGLOSSUM	BOMBYLANS	9
LEPIDOPTERA	SPHINGIDAE	MACROGLOSSUM	PYRRHOSTICTA	10
LEPIDOPTERA	SPHINGIDAE	MANDUCA	QUINQUEMACULATA	9
LEPIDOPTERA	SPHINGIDAE	MANDUCA	SEXTA	5 9 12 17
LEPIDOPTERA	SPHINGIDAE	PACHYSPHINX	MODESTA	5
LEPIDOPTERA	SPHINGIDAE	PERGESA	ELPENOR	(SEE DEILEPHILA ELPENOR)
LEPIDOPTERA	SPHINGIDAE	PROSERPINUS	PROSERPINA	16
LEPIDOPTERA	SPHINGIDAE	PROTOPARCE	QUINQUEMACULATA	(SEE MANDUCA QUINQUEMACULATA)
LEPIDOPTERA	SPHINGIDAE	PROTOPARCE	SEXTA	(SEE MANDUCA SEXTA)
LEPIDOPTERA	SPHINGIDAE	PSILOGRAMMA	INCRETA	10
LEPIDOPTERA	SPHINGIDAE	PSILOGRAMMA	MENEPHRON	9
LEPIDOPTERA	SPHINGIDAE	SMERINTHUS	OCELLATA	5 12 16
LEPIDOPTERA	SPHINGIDAE	SMERINTHUS	OCELLATA ATLANTICUS	12 16
LEPIDOPTERA	SPHINGIDAE	SPHINX	LIGUSTRI	5 12
LEPIDOPTERA	SPHINGIDAE	SPHINX	PINASTRI	(SEE HYLOICUS PINASTRI)
LEPIDOPTERA	SPHINGIDAE	THERETRA	JAPONICA	12
LEPIDOPTERA	SPHINGIDAE	THERETRA	NESSUS	10
LEPIDOPTERA	SPHINGIDAE	THERETRA	OLDENLANDIAE	10
LEPIDOPTERA	THAUMETOPOEIDAE	THAUMETOPOEA	PITYOCAMPA	5 9 12 13
LEPIDOPTERA	THAUMETOPOEIDAE	THAUMETOPOEA	PROCESSIONEA	5 12
LEPIDOPTERA	THAUMETOPOEIDAE	THAUMETOPOEA	WILKINSONI	5 12
LEPIDOPTERA	THYATIRIDAE	EUTHYATIRA	PUDENS	12
LEPIDOPTERA	TINEIDAE	TINEA	COLUMBARIELLA	16
LEPIDOPTERA	TINEIDAE	TINEA	PELLIONELLA	5 10 12
LEPIDOPTERA	TINEIDAE	TINEOLA	BISSELLIELLA	5 12 16
LEPIDOPTERA	TORTRICIDAE	ACLERIS	GLOVERANA	12
LEPIDOPTERA	TORTRICIDAE	ACLERIS	VARIANA	9 12
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	FASCIATA	5 9 19
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	ORANA	5 9 12 19
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	PRIVATANA	(SEE ADOXOPHYES ORANA)
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	RETICULANA	(SEE ADOXOPHYES ORANA)
LEPIDOPTERA	TORTRICIDAE	AMELIA	PALLORANA	9
LEPIDOPTERA	TORTRICIDAE	APHANIA	GEMINATA	10
LEPIDOPTERA	TORTRICIDAE	ARCHIPPUS	BREVIPLICANUS	9 19
LEPIDOPTERA	TORTRICIDAE	ARCHIPPUS	ISSHIKII	19
LEPIDOPTERA	TORTRICIDAE	ARCHIPPUS	PACKARDIANUS	9
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	ARGYROSPILA	9
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	CERASIVORANUS	12
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	CRATAEGANA	16
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	FUSCOCUPREANUS	19
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	LONGICELLANA	9
LEPIDOPTERA	TORTRICIDAE	ARGYROPOLOE	LEUCOTRETA	(SEE CRYPTOPHLEBIA LEUCOTRETA)
LEPIDOPTERA	TORTRICIDAE	ARGYROTAENIA	VELUTINANA	9
LEPIDOPTERA	TORTRICIDAE	CACOEZIA	MURINANA	(SEE CHORISTONEURA MURINANA)
LEPIDOPTERA	TORTRICIDAE	CARPOCAPSA	POMONELLA	(SEE CYDIA POMONELLA)
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	BIENNIS	19
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	CONFLICTANA	9 12 19
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	DIVERSANA	12 19
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	FUMIFERANA	5 9 10 12 13 19
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	MURINANA	9 12 16
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	OCCIDENTALIS	9 12
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	PINUS	12
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	ROSACEANA	12
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	VIRIDIS	9
LEPIDOPTERA	TORTRICIDAE	CLEPSIS	PERSICANA	9
LEPIDOPTERA	TORTRICIDAE	CRYPTOPHLEBIA	LEUCOTRETA	5 9
LEPIDOPTERA	TORTRICIDAE	CYDIA	NIGRICANA	9
LEPIDOPTERA	TORTRICIDAE	CYDIA	PHASEOLI	(SEE LATHRONYMPHA PHASEOLI)
LEPIDOPTERA	TORTRICIDAE	CYDIA	POMONELLA	9 12 16
LEPIDOPTERA	TORTRICIDAE	EPINOTIA	APOREMA	9
LEPIDOPTERA	TORTRICIDAE	EPIPHYAS	POSTVITTANA	12
LEPIDOPTERA	TORTRICIDAE	EUCOSMA	ANCYROTA	10
LEPIDOPTERA	TORTRICIDAE	EUCOSMA	GRISEANA	(SEE ZEIRAPHERA DINIANA)
LEPIDOPTERA	TORTRICIDAE	EXARTEMA	APPENDICEUM	9

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	TORTRICIDAE	GRAPHOLITHA	MOLESTA	9
LEPIDOPTERA	TORTRICIDAE	GRISELDA	RADICANA	9
LEPIDOPTERA	TORTRICIDAE	HOMONA	COFFEARIA	9 10 16
LEPIDOPTERA	TORTRICIDAE	HOMONA	MAGNANIMA	5 9 12 19
LEPIDOPTERA	TORTRICIDAE	LASPEYRESIA	POMONELLA	(SEE CYDIA POMONELLA)
LEPIDOPTERA	TORTRICIDAE	LATHRONYMPHA	PHASEOLI	9
LEPIDOPTERA	TORTRICIDAE	LOBESIA	BOTRANA	5 9
LEPIDOPTERA	TORTRICIDAE	MEROPHYAS	DIVULSANA	12
LEPIDOPTERA	TORTRICIDAE	PANDEMIS	HEPARANA	12
LEPIDOPTERA	TORTRICIDAE	PANDEMIS	LAMPROSANA	12
LEPIDOPTERA	TORTRICIDAE	PLATYNOTA	IDAEUSALIS	5 12
LEPIDOPTERA	TORTRICIDAE	POLYCHROSIS	BOTRANA	(SEE LOBESIA BOTRANA)
LEPIDOPTERA	TORTRICIDAE	PTYCHOLOMOIDES	AERIFERANA	12
LEPIDOPTERA	TORTRICIDAE	RHYACIONIA	BUOLIANA	9
LEPIDOPTERA	TORTRICIDAE	RHYACIONIA	DUPLANA	9 12
LEPIDOPTERA	TORTRICIDAE	RHYACIONIA	FRUSTRANA	9
LEPIDOPTERA	TORTRICIDAE	SCIAPHILA	DUPLEX	9
LEPIDOPTERA	TORTRICIDAE	SPARGANOTHIS	PETTITANA	12
LEPIDOPTERA	TORTRICIDAE	SPIILONOTA	OCELLANA	12
LEPIDOPTERA	TORTRICIDAE	TORTRIX	LOEFLINGIANA	12 16
LEPIDOPTERA	TORTRICIDAE	TORTRIX	VIRIDANA	5 12 16
LEPIDOPTERA	TORTRICIDAE	ZEIRAPHERA	DINIANA	9 12 16 19
LEPIDOPTERA	TORTRICIDAE	ZEIRAPHERA	PSEUDOTSUGANA	12
LEPIDOPTERA	TORTRICIDAE	ZEIRAPHERA	SP.	9
LEPIDOPTERA	YPONOMEUTIDAE	PRAYS	OLEELLUS	16
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	COGNATELLA	12
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	EVONYMELLA	12
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	MALINELLUS	12
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	MAYUMIVORELLUS	10
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	PADELLA	12
LEPIDOPTERA	ZYGAENIDAE	AGLAOPE	INFAUSTA	5
LEPIDOPTERA	ZYGAENIDAE	ARTONA	FUNERALIS	9 10
LEPIDOPTERA	ZYGAENIDAE	HARRISINA	BRILLIANS	9
LEPIDOPTERA	ZYGAENIDAE	ILLIBERIS	PRUNI	10
LEPIDOPTERA	ZYGAENIDAE	ILLIBERIS	PSYCHINA	(SEE ILLIBERIS PRUNI)
LEPIDOPTERA	ZYGAENIDAE	PHAUDA	FLAMMANS	12
LEPIDOPTERA	ZYGAENIDAE	PIDORUS	GLAUCOPIS ATRATUS	10
LEPIDOPTERA	ZYGAENIDAE	PRYERIA	SINICA	10
NEUROPTERA	CHRYSOPTERIDAE	CHRYSOPTER	PERLA	5 12
NEUROPTERA	HEMEROBIIDAE	HEMEROBIUS	STIGMA	5 12
NEUROPTERA	MYRMELEONTIDAE	HAGENOMYIA	MICANS	16
ODONATA	LIBELLULIDAE	LEUCORRHINIA	DUBIA	13
ORTHOPTERA	ACRIDIDAE	ACRIDA	TURRITA	10
ORTHOPTERA	ACRIDIDAE	AMPHITORNUS	COLORADUS	4
ORTHOPTERA	ACRIDIDAE	ARPHIA	CONSPERSA	19
ORTHOPTERA	ACRIDIDAE	AULOCARA	ELLIOTTI	4
ORTHOPTERA	ACRIDIDAE	CHORTOICETES	TERMINIFERA	13
ORTHOPTERA	ACRIDIDAE	GOMPHOCERUS	SIBIRICUS	19
ORTHOPTERA	ACRIDIDAE	LOCUSTA	MIGRATORIA	17 19
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	BIVITTATUS	4 13 19
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	DAWSONI	4
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	DIFFERENTIALIS	4 19
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	FEMURRUBRUM	4
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	SANGUINIPES	4 19
ORTHOPTERA	ACRIDIDAE	PHOETALIOTES	NEBRASCENSIS	19
ORTHOPTERA	ACRIDIDAE	SCHISTOCERCA	AMERICANA	4 13 19
ORTHOPTERA	ACRIDIDAE	SCHISTOCERCA	VAGA	4
ORTHOPTERA	ACRIDIDAE	XANTHIPPIUS	CORALLIPES	19
ORTHOPTERA	BACILLIDAE	BACILLUS	ROSSII	13 17
ORTHOPTERA	BLABERIDAE	LEUCOPHAEA	MADERAE	17
ORTHOPTERA	BLATTIDAE	PERIPLANETA	AMERICANA	13
ORTHOPTERA	BLATTIDAE	PERIPLANETA	AUSTRALASIAE	13
ORTHOPTERA	BLATTIDAE	PERIPLANETA	BRUNNEA	13
ORTHOPTERA	BLATTIDAE	PERIPLANETA	FULIGINOSA	13
ORTHOPTERA	BLATTIDAE	PERIPLANETA	JAPONICA	13

ORDER	FAMILY	GENUS	SPECIES	DISEASES
ORTHOPTERA	GRYLLIDAE	ACHETA	DOMESTICUS	6 13 17
ORTHOPTERA	GRYLLIDAE	GRYLLUS	BIMACULATUS	13 15
ORTHOPTERA	GRYLLIDAE	GRYLLUS	CAMPESTRIS	13
ORTHOPTERA	GRYLLIDAE	PTERONEMOBIUS	NIGROVUS	13
ORTHOPTERA	GRYLLIDAE	PTERONEMOBIUS	SP.	13
ORTHOPTERA	GRYLLIDAE	TELEOGRYLLUS	COMMODUS	13 15
ORTHOPTERA	GRYLLIDAE	TELEOGRYLLUS	OCEANICUS	13 15
ORTHOPTERA	MANTIDAE	HOLAPTILON	PUSILLULUM	17
ORTHOPTERA	PYRGOMORPHIDAE	ATRACTOMORPHA	BEDELI	10
THYSANOPTERA	THRIPIIDAE	FRANKLINIELLA	FUSCA	17
THYSANURA	PRAEMACHILIDAE	DILTA	HIBERNICA	12
TRICHOPTERA	LIMNephilidae	NEOPHYLAX	SP.	12



## **Appendix 2**

### **Alphabetical List of Hosts by Specific Names**



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	PYRALIDAE	DIORYCTRIA	ABIETELLA	9
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	ABIETIS	12 16
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	ABIETIS	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	ABIETIS	12 16
LEPIDOPTERA	NOCTUIDAE	ACRONICTA	ACERIS	12
LEPIDOPTERA	ARCTIIDAE	ESTIGMENE	ACREA	5 9 10 12 16 19
LEPIDOPTERA	PYRALIDAE	BLEPHAROMASTIX	ACUTANGULALIS	16
ISOPTERA	TERMOPSIDAE	POROTERMES	ADAMSONI	17
LEPIDOPTERA	SATYRIDAE	PARARGE	AEGERIA	5
DIPTERA	CULICIDAE	AEDES	AEGYPTI	5 6 10 12 13 17 19
LEPIDOPTERA	TORTRICIDAE	PTYCHOLOMOIDES	AERIFERANA	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	AFFINIS	3
LEPIDOPTERA	NOCTUIDAE	ARGYROGRAMMA	AGNATA	(SEE PLUSIA AGNATA)
LEPIDOPTERA	NOCTUIDAE	PLUSIA	AGNATA	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	AGRAMMA	(SEE ANADEVIDIA PEONIS)
HYMENOPTERA	APIIDAE	BOMBUS	AGRORUM	1
LEPIDOPTERA	LYMANTRIIDAE	ARCTORNIS	ALBA	12
LEPIDOPTERA	NOCTUIDAE	HELIOPHOBUS	ALBICOLON	5
DIPTERA	CULICIDAE	ANOPHELES	ALBIMANUS	10 19
LEPIDOPTERA	NOCTUIDAE	ATHETIS	ALBINA	9
LEPIDOPTERA	ARCTIIDAE	AMSACTA	ALBISTRIGA	12
LEPIDOPTERA	HEPTALIDAE	ONCOPERA	ALBOGUTTATA	19
COLEOPTERA	SCARABAEIDAE	DERMOLEPIDA	ALBOHIRTUM	19
DIPTERA	CULICIDAE	AEDES	ALBOPICTUS	6 10 11 13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ALGONQUIN	3
LEPIDOPTERA	LIMACODIDAE	NIPHADOLEPIS	ALIANATA	17
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	ALPICOLA	12
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	ALPINA	16
LEPIDOPTERA	NOTODONTIDAE	STAURUPUS	ALTERNUS	16
HYMENOPTERA	BRACONIDAE	CHELONUS	ALTITUDINIS	13
LEPIDOPTERA	ARCTIIDAE	DIONYCHOPUS	AMASIS	9 13
LEPIDOPTERA	NOCTUIDAE	ATHETIS	AMBIGUA	(SEE HOPLDRINA AMBIGUA)
LEPIDOPTERA	NOCTUIDAE	HOPLDRINA	AMBIGUA	12
LEPIDOPTERA	COCHYLIDAE	CLYSIANA	AMBIGUELLA	(SEE EUPOECILIA AMBIGUELLA)
LEPIDOPTERA	COCHYLIDAE	EUPOECILIA	AMBIGUELLA	16
DIPTERA	CULICIDAE	TOXORHYNCHITES	AMBOINENSIS	3 13
ORTHOPTERA	BLATTIDAE	PERIPLANETA	AMERICANA	13
ORTHOPTERA	ACRIDIDAE	SCHISTOCERCA	AMERICANA	4 13 19
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	AMERICANUM	5 12 13 16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	AMERICANUM	(SEE NEODIPRION TAEDAE TAEDAE)
LEPIDOPTERA	GEOMETRIDAE	HYPERETIS	AMICARIA	12
LEPIDOPTERA	ANTHELIDAE	PTEROLOCERA	AMPLICORNIS	12
LEPIDOPTERA	NOTODONTIDAE	CLOSTERA	ANACHORETA	(SEE PYGAERA ANACHORETA)
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANACHORETA	9 10
LEPIDOPTERA	PAPILLIONIDAE	PAPILIO	ANACTUS	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ANANASSAE	13
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	ANARTOIDES	12 13
LEPIDOPTERA	NOTODONTIDAE	CLOSTERA	ANASTOMOSIS	(SEE PYGAERA ANASTOMOSIS)
LEPIDOPTERA	NOTODONTIDAE	MELALOPHA	ANASTOMOSIS	(SEE PYGAERA ANASTOMOSIS)
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANASTOMOSIS	5 9 12 17
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANASTOMOSIS ORIENTALIS	5 12
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	ANASTOMOSIS TRISTIS	5 12
LEPIDOPTERA	NOCTUIDAE	APAMEA	ANCEPS	9 12
LEPIDOPTERA	TORTRICIDAE	EUCOSMA	ANCYROTA	10
LEPIDOPTERA	NOCTUIDAE	PRODNA	ANDROGEA	9
DIPTERA	SCIARIDAE	RHYNCHOSCIARA	ANGELAE	12 17
LEPIDOPTERA	PSYCHIDAE	OREOPSYCHE	ANGUSTELLA	19
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	ANKERARIA	12
DIPTERA	CULICIDAE	AEDES	ANNANDALEI	12
DIPTERA	CULICIDAE	CULISETA	ANNULATA	6 10
LEPIDOPTERA	GEOMETRIDAE	EUPITHECIA	ANNULATA	12
DIPTERA	CULICIDAE	AEDES	ANNULIPES	10
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	ANNULIPES	13
LEPIDOPTERA	NYMPHALIDAE	NYMPHALIS	ANTIOPA	5 9 12 16
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	ANTIQUA	5 12 16
COLEOPTERA	SCARABAEIDAE	PHYLLOPHAGA	ANXIA	17



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	LASIOCAMPIDAE	ENTOMETA	APICALIS	13
LEPIDOPTERA	LIMACODIDAE	SIBINE	APICALIS	5
LEPIDOPTERA	TORTRICIDAE	EPINOTIA	APOREMA	9
LEPIDOPTERA	TORTRICIDAE	EXARTEMA	APPENDICEUM	9
DIPTERA	CHAOBORIDAE	CORETHRELLA	APPENDICULATA	10
COLEOPTERA	SCARABAEIDAE	HETERONYCHUS	ARATOR	10 11 13
DIPTERA	CERATOPOGONIDAE	CULICOIDES	ARBORICOLA	10
LEPIDOPTERA	LYCAENIDAE	OGYRIS	ARBROTA	13
LEPIDOPTERA	CRYPTOPHASIDAE	OPISINA	ARENOSSELLA	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	ARGENTATA	12
LEPIDOPTERA	ARCTIIDAE	HALISIDOTA	ARGENTATA	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	ARGENTIFERA	12
HYMENOPTERA	BRACONIDAE	ASCOGASTER	ARGENTIFRONS	13
LEPIDOPTERA	NOCTUIDAE	ALABAMA	ARGILLACEA	12 16
DIPTERA	SIMULIIDAE	SIMULIUM	ARGYREATUM	5
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	ARGYROSPILA	9
LEPIDOPTERA	GEOMETRIDAE	GONODONTIS	ARIDA	10
LEPIDOPTERA	GEOMETRIDAE	HETEROLOCHA	ARISTONARIA NIPHONICA	10
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	ARMIGERA	5 9 10 12 13
LEPIDOPTERA	PSYCHIDAE	CANEPHORA	ASIATICA	12
LEPIDOPTERA	LIMACODIDAE	THOSEA	ASIGNA	13
LEPIDOPTERA	ETHMIIDAE	ETHMIA	ASSAMENSIS	10
LEPIDOPTERA	NOTODONTIDAE	PHALERA	ASSIMILIS	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	ASSULTA	12
LEPIDOPTERA	NYMPHALIDAE	PYRAMEIS	ATALANTA	(SEE VANESSA ATALANTA)
LEPIDOPTERA	NYMPHALIDAE	VANESSA	ATALANTA	12 16
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ATHABASCA	3
LEPIDOPTERA	GEOMETRIDAE	JANKOWSKIA	ATHLETA	12
LEPIDOPTERA	NOCTUIDAE	ADISURA	ATKINSONI	12
DIPTERA	CULICIDAE	AEDES	ATROPALPUS	12
LEPIDOPTERA	SPHINGIDAE	ACHERONTIA	ATROPOS	13
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	ATTENUATUS	19
LEPIDOPTERA	SATURNIIDAE	AUTOMERIS	AURANTIACA	5
DIPTERA	SIMULIIDAE	SIMULIUM	AUREUM	5
COLEOPTERA	BUPRESTIDAE	TRACHYS	AURICOLLIS	10
LEPIDOPTERA	LYMANTRIIDAE	IVELA	AURIPES	12
ORTHOPTERA	BLATTIDAE	PERIPLANETA	AUSTRALASIAE	13
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	AUSTRALIS	12
COLEOPTERA	SCARABAEIDAE	SCAPANES	AUSTRALIS GROSSEPUNCTATUS	11
LEPIDOPTERA	GEOMETRIDAE	OPORINIA	AUTUMNATA	5 12
LEPIDOPTERA	NOCTUIDAE	CHORIZAGROTIS	AUXILIARIS	(SEE EUMEOA AUXILIARIS)
LEPIDOPTERA	NOCTUIDAE	EUXOA	AUXILIARIS	9 12 13 16 19
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	AXUTHA	5 12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	AZTECA	3
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	BADIA	12
LEPIDOPTERA	LIMACODIDAE	THOSEA	BAIBARANA	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	BALLUCA	12
LEPIDOPTERA	PYRALIDAE	NAGIA	BALTEATA	10
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	BASIFLAVA	12
LEPIDOPTERA	NOCTUIDAE	ARGYROGRAMMA	BASIGERA	12
LEPIDOPTERA	NOCTUIDAE	HADENA	BASILINEA	9
LEPIDOPTERA	LASIOCAMPIDAE	LECHRIOLEPIS	BASIRUFA	12
COLEOPTERA	SCARABAEIDAE	OTHNONIUS	BATESI	19
ORTHOPTERA	PYRGOMORPHIDAE	ATRAC TOMORPHA	BEDELI	10
LEPIDOPTERA	GEOMETRIDAE	PERO	BEHRENSARIUS	12
HYMENOPTERA	ICHNEUMONIDAE	OLESICAMPE	BENEFAC TOR	13
LEPIDOPTERA	GEOMETRIDAE	BISTON	BETULARIA	5 12
LEPIDOPTERA	LIMACODIDAE	PARASA	BICOLOR	9
LEPIDOPTERA	NOTODONTIDAE	LEUCODONTA	BICOLORIA	13
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	BIENNIS	19
DIPTERA	DROSOPHILIDAE	DROSOPHILA	BIFASCIATA	17
LEPIDOPTERA	NOTODONTIDAE	CERURA	BIFIDA	(SEE CERURA HERMELINA)
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	BILOBA	12 16
LEPIDOPTERA	NOTODONTIDAE	SEMI DONTA	BILOBA	12
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	BIMACULATA	12
ORTHOPTERA	GRYLLIDAE	GRYLLUS	BIMACULATUS	13 15

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	EARIAS	BIPLAGA	5
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	BIPUNCTAPEX	12
LEPIDOPTERA	EUPTEROTIDAE	ANDRACA	BIPUNCTATA	9
LEPIDOPTERA	TINEIDAE	TINEOLA	BISSELLIELLA	5 12 16
LEPIDOPTERA	GEOMETRIDAE	BOARMIA	BISTORTATA	12
LEPIDOPTERA	GEOMETRIDAE	GLENA	BISULCA	9
LEPIDOPTERA	LIMACODIDAE	THOSEA	BISURA	17
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	BIVITTATUS	4 13 19
HYMENOPTERA	BRACONIDAE	CHELONUS	BLACKBURNI	13
LEPIDOPTERA	PYRALIDAE	OMIODES	BLACKBURNI	17
COLEOPTERA	SCARABAEIDAE	ORYCTES	BOAS	11 20
LEPIDOPTERA	SPHINGIDAE	MACROGLOSSUM	BOMBYLANS	9
COLEOPTERA	SCARABAEIDAE	DEMODENA	BORANENSIS	19
LEPIDOPTERA	TORTRICIDAE	LOBESIA	BOTRANA	5 9
LEPIDOPTERA	TORTRICIDAE	POLYCHROSIS	BOTRANA	(SEE LOBESIA BOTRANA)
DIPTERA	CULICIDAE	ANOPHELES	BRADLEYI	5
DIPTERA	CHAOBORIDAE	CORETHRELLA	BRAKELEYI	10
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	BRASSICAE	(SEE TRICHOPLUSIA NI)
LEPIDOPTERA	NOCTUIDAE	BARATHRA	BRASSICAE	(SEE MAMESTRA BRASSICAE)
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	BRASSICAE	5 6 9 10 12 13
LEPIDOPTERA	PIERIDAE	PIERIS	BRASSICAE	5 9 10 13 17
LEPIDOPTERA	NOCTUIDAE	PLUSIA	BRASSICAE	(SEE TRICHOPLUSIA NI)
LEPIDOPTERA	PIERIDAE	PIERIS	BRASSICAE CHEIRANTHI	9
DIPTERA	CULICIDAE	TOXORHYNCHITES	BREVIPALPIS	12
LEPIDOPTERA	TORTRICIDAE	ARCHIPPUS	BREVIPLICANUS	9 19
LEPIDOPTERA	ZYGAENIDAE	HARRISINA	BRILLIANS	9
LEPIDOPTERA	GEOMETRIDAE	OPEROPHTERA	BRUCEATA	5 12
LEPIDOPTERA	GEOMETRIDAE	OPEROPHTERA	BRUMATA	5 12 16 17 19
ORTHOPTERA	BLATTIDAE	PERIPLANETA	BRUNNEA	13
LEPIDOPTERA	NOTODONTIDAE	PHALERA	BUCEPHALA	5 12
LEPIDOPTERA	TORTRICIDAE	RHYACIONIA	BUOLIANA	9
DIPTERA	DROSOPHILIDAE	DROSOPHILA	BUSCKII	3
LEPIDOPTERA	NYMPHALIDAE	POLYGONIA	C-ALBUM	5 12
LEPIDOPTERA	NOCTUIDAE	AMATHES	C-NIGRUM	5 9 12
LEPIDOPTERA	NOCTUIDAE	XESTIA	C-NIGRUM	(SEE AMATHES C-NIGRUM)
LEPIDOPTERA	GEOMETRIDAE	SABULODES	CABERATA	9 16
LEPIDOPTERA	PYRALIDAE	CACTOBLASTIS	CACTORUM	5
LEPIDOPTERA	ARCTIIDAE	ARCTIA	CAJA	5 12 16
LEPIDOPTERA	NOCTUIDAE	SESAMIA	CALAMISTIS	5 12 13
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	CALIFORNICA	5 9 12 13
LEPIDOPTERA	DIOPTIDAE	PHRYGANIDIA	CALIFORNICA	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	CALIFORNICUM	12
DIPTERA	SIMULIIDAE	SIMULIUM	CALLIDUM	10
LEPIDOPTERA	NOTODONTIDAE	LOPHOPTERYX	CAMELINA	12
ORTHOPTERA	GRYLLIDAE	GRYLLUS	CAMPESTRIS	13
HYMENOPTERA	PAMPHILIIDAE	LYDA	CAMPESTRIS	(SEE CEPHALCIA ABIETIS)
LEPIDOPTERA	LIMACODIDAE	THOSEA	CANA	17
HYMENOPTERA	BRACONIDAE	MICROGASTER	CANADENSIS	13
LEPIDOPTERA	LYMANTRIIDAE	LEUCOMA	CANDIDA	5 12
LEPIDOPTERA	NOCTUIDAE	DIARSIA	CANESCENS	10
HYMENOPTERA	ICHNEUMONIDAE	VENTURIA	CANESCENS	13
LEPIDOPTERA	GEOMETRIDAE	NEPTYIA	CANOSARIA	16
DIPTERA	CULICIDAE	AEDES	CANTANS	6 10
DIPTERA	CULICIDAE	AEDES	CANTATOR	5
LEPIDOPTERA	LASIOCAMPIDAE	PACHYPASA	CAPENSIS	12 13
DIPTERA	TEPHRITIDAE	CERATITIS	CAPITATA	3 13
LEPIDOPTERA	NOTODONTIDAE	LOPHOPTERYX	CAPUCINA	5
LEPIDOPTERA	PIERIDAE	EUCHLOE	CARDAMINES	5
LEPIDOPTERA	NYMPHALIDAE	PYRAMEIS	CARDUI	(SEE VANESSA CARDUI)
LEPIDOPTERA	NYMPHALIDAE	VANESSA	CARDUI	5 10 12 16
LEPIDOPTERA	GEOMETRIDAE	ACIDALIA	CARTICCARIA	12
LEPIDOPTERA	ARCTIIDAE	HALISIDOTA	CARYAE	12
DIPTERA	CULICIDAE	AEDES	CASPIUS	10
DIPTERA	CULICIDAE	AEDES	CASPIUS CASPIUS	10
DIPTERA	CULICIDAE	AEDES	CASPIUS DORSALIS	(SEE AEDES DORSALIS)
LEPIDOPTERA	BRASSOLIDAE	OPSIPHANES	CASSINA	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	LIMACODIDAE	DORATIFERA	CASTA	12
LEPIDOPTERA	LASIOCAMPIDAE	TICERA	CASTANEA	12
LEPIDOPTERA	LIMACODIDAE	SPATULIFIMBRIA	CASTANEICEPS	17
DIPTERA	CULICIDAE	AEDES	CATAPHYLLA	10
LEPIDOPTERA	GEOMETRIDAE	CINGILIA	CATENARIA	12
LEPIDOPTERA	PYRALIDAE	CADRA	CAUTELLA	5 9 12
LEPIDOPTERA	PYRALIDAE	EPHESTIA	CAUTELLA	(SEE CADRA CAUTELLA)
DIPTERA	CERATOPOGONIDAE	CULICOIDES	CAVATICUS	13
LEPIDOPTERA	SATURNIIDAE	HYALOPHORA	CECROPIA	5 12 13
LEPIDOPTERA	SATURNIIDAE	PLATYSAMIA	CECROPIA	(SEE HYALOPHORA CECROPIA)
LEPIDOPTERA	NYMPHALIDAE	ASTEROCAMPA	CELTIS	12
LEPIDOPTERA	NOCTUIDAE	SELEPA	CELTIS	9
LEPIDOPTERA	PYRALIDAE	CORCYRA	CEPHALONICA	12
HYMENOPTERA	APIIDAE	APIS	CERANA	10 13 18
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	CERASIVORANUS	12
LEPIDOPTERA	LIMACODIDAE	THOSEA	CERVINA	17
LEPIDOPTERA	HEPIALIDAE	WISEANA	CEKVINATA	9 10 12 19
LEPIDOPTERA	NOCTUIDAE	CHRYSODEIXIS	CHALCITES	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	CHALCYTES	(SEE CHRYSODEIXIS CHALCITES)
LEPIDOPTERA	NOCTUIDAE	MOMA	CHAMPA	12
LEPIDOPTERA	NOCTUIDAE	TRICHOSEA	CHAMPA	(SEE MOMA CHAMPA)
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	CHRYSORRHOEA	5 12 16
LEPIDOPTERA	PIERIDAE	COLIAS	CHRYSOTHEME CHRYSOTHEME	16
HEMIPTERA	CICADELLIDAE	NEPHOTETTIX	CINCTICEPS	10
LEPIDOPTERA	GEOMETRIDAE	AOCHEIMA	CINERARIUS	12
DIPTERA	CULICIDAE	AEDES	CINEREUS	6
ACARI	TETRANYCHIDAE	TETRANYCHUS	CINNABARINUS	13 17
COLEOPTERA	CERAMBYCIDAE	TETROPIUM	CINNAMOPTERUM	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	CIRCUMFLEXA	9
ACARI	TETRANYCHIDAE	PANONYCHUS	CITRI	13 17
LEPIDOPTERA	NOCTUIDAE	SPAELOTIS	CLANDESTINA	16
LEPIDOPTERA	HESPERIIDAE	EPARGYREUS	CLARUS	12
DIPTERA	CERATOPOGONIDAE	CULICOIDES	CLASTRIERI	10
COLEOPTERA	CERAMBYCIDAE	STENODRYAS	CLAVIGERA	10
ACARI	DAMAEIDAE	DAMAEUS	CLAVIPES	17
LEPIDOPTERA	PYRALIDAE	ALGEDONIA	COCLESALIS	10
LEPIDOPTERA	NYMPHALIDAE	JUNONIA	COENIA	6 9 12 16
LEPIDOPTERA	NOCTUIDAE	ARCTE	COERULEA	5 10
LEPIDOPTERA	TORTRICIDAE	HOMONA	COFFEARIA	9 10 16
LEPIDOPTERA	GEOMETRIDAE	AMPHIDASIS	COGNATARIA	12
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	COGNATELLA	12
ORTHOPTERA	ACRIDIDAE	AMPHITORNUS	COLORADUS	4
LEPIDOPTERA	TINEIDAE	TINEA	COLUMBARIELLA	16
HEMIPTERA	BELOSTOMATIDAE	LETHOCERUS	COLUMBIAE	10
ORTHOPTERA	GRYLLIDAE	TELEOGRYLLUS	COMMODUS	13 15
LEPIDOPTERA	NOTODONTIDAE	SCHIZURA	CONCINNA	5
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	CONFIGURATA	9 12
DIPTERA	CULICIDAE	PSOROPHORA	CONFINNIS	5 10 12 17
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	CONFLICTANA	9 12 19
LEPIDOPTERA	HESPERIIDAE	POTANTHUS	CONFUCIUS FLAVA	(SEE POTANTHUS FLAVUM)
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	CONFUSA	12
HYMENOPTERA	BRACONIDAE	APANTELES	CONGREGATUS	13 17
HYMENOPTERA	FORMICIDAE	LEPTOTHORAX	CONGRUUS	13
LEPIDOPTERA	ARGYRESTHIIDAE	ARGYRESTHIA	CONJUGELLA	12
LEPIDOPTERA	NOCTUIDAE	CATOCALA	CONJUNCTA	12
LEPIDOPTERA	LIMACODIDAE	LATOIA	CONSOCIA	(SEE PARASA CONSOCIA)
LEPIDOPTERA	LIMACODIDAE	PARASA	CONSOCIA	9 12
ORTHOPTERA	ACRIDIDAE	ARPHIA	CONSPERSA	19
LEPIDOPTERA	LIMACODIDAE	NAROSA	CONSPERSA	17
LEPIDOPTERA	NOCTUIDAE	XYLONYGES	CONSPICILLARIS	5
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	CONSTRUCTUM	12
LEPIDOPTERA	LIMACODIDAE	SCOPELODES	CONTRACTA	5 12
LEPIDOPTERA	NOCTUIDAE	PSEUDALETIA	CONVECTA	9 12
LEPIDOPTERA	SPHINGIDAE	HERSE	CONVOLVULI	5
ORTHOPTERA	ACRIDIDAE	XANTHIPPIUS	CORALLIPES	19
LEPIDOPTERA	PSYCHIDAE	MAHASENA	CORBETTI	17



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	PYRALIDAE	SCELIODES	CORDALIS	12
LEPIDOPTERA	DANAIDAE	EUPLOEA	COREA	13
LEPIDOPTERA	NOCTUIDAE	OPHIUSA	CORONATA	17
LEPIDOPTERA	COSSIDAE	COSSUS	COSSUS	12
HYMENOPTERA	VESPIDAE	VESPA	CRABRO	15
HYMENOPTERA	BRACONIDAE	APANTELES	CRASSICORNIS	13 17
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	CRATAEGANA	16
LEPIDOPTERA	PIERIDAE	APORIA	CRATAEGI	5 12 16
LEPIDOPTERA	GEOMETRIDAE	ECTROPIS	CREPUSCULARIA	12 16
LEPIDOPTERA	NOCTUIDAE	SESAMIA	CRETICA	9
HYMENOPTERA	TENTHREDINIDAE	HEMICHROA	CROCEA	12
HYMENOPTERA	BRACONIDAE	MICROPLITIS	CROCEIPES	13 17
DIPTERA	CULICIDAE	ANOPHELES	CRUCIANS	5 12
DIPTERA	CHAOBORIDAE	CHAOBORUS	CRYSTALLINUS	13
DIPTERA	CERATOPOGONIDAE	CULICOIDES	CUBITALIS	10
DIPTERA	CHAOBORIDAE	MOCHLONYX	CULICIFORMIS	(SEE MOCHLONYX VELUTINUS)
LEPIDOPTERA	ARCTIIDAE	HYPHANTRIA	CUNEA	5 9 12 16
COLEOPTERA	SCARABAEIDAE	ANOMALA	CUPREA	19
LEPIDOPTERA	ARGYRESTHIIDAE	ARGYRESTHIA	CUPRESSELLA	9
HYMENOPTERA	ICHNEUMONIDAE	BATHYPLECTES	CURCULIONIS	13
LEPIDOPTERA	NOCTUIDAE	XYLENA	CURVIMACULA	12
LEPIDOPTERA	SATURNIIDAE	PHILOSAMIA	CYNTHIA	(SEE SAMIA CYNTHIA)
LEPIDOPTERA	SATURNIIDAE	SAMIA	CYNTHIA	5 12 13 16
LEPIDOPTERA	SATURNIIDAE	PHILOSAMIA	CYNTHIA PRYERI	(SEE SAMIA PRYERI)
LEPIDOPTERA	SATURNIIDAE	NUDAURELIA	CYTHAREA CAPENSIS	(SEE N. CYTHAREA CYTHAREA)
LEPIDOPTERA	SATURNIIDAE	NUDAURELIA	CYTHAREA CLARKI	13
LEPIDOPTERA	SATURNIIDAE	NUDAURELIA	CYTHAREA CYTHAREA	5 13 16
LEPIDOPTERA	PIERIDAE	PONTIA	DAPLIDICE	9
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	DAUNIS	12
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	DAWSONI	4
COLEOPTERA	CHRYSOMELIDAE	LEPTINOTARSA	DECEMLINEATA	10
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	DECORUS	19
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	DEFOLIARIA	12
LEPIDOPTERA	GEOMETRIDAE	HIBERNIA	DEFOLIARIA	(SEE ERANNIS DEFOLIARIA)
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	DEMOLEUS	12
LEPIDOPTERA	LIMACODIDAE	APODA	DENTATUS	10
COLEOPTERA	CURCULIONIDAE	CURCULIO	DENTIPES	10
LEPIDOPTERA	PYRALIDAE	NYMPHULA	DEPUNCTALIS	12
LEPIDOPTERA	PYRALIDAE	NOTARCHA	DEROGATA	10
HYMENOPTERA	TENTHREDINIDAE	ANOPLONYX	DESTRUCTOR	5
DIPTERA	CULICIDAE	AEDES	DETRITUS	10
LEPIDOPTERA	NOCTUIDAE	CRYMODES	DEVASTATOR	5
LEPIDOPTERA	NYMPHALIDAE	ARGYNNIS	DIA	(SEE BOLORIA DIA)
LEPIDOPTERA	NYMPHALIDAE	BOLORIA	DIA	5
LEPIDOPTERA	NYMPHALIDAE	CLOSSIANA	DIA	(SEE BOLORIA DIA)
COLEOPTERA	SCARABAEIDAE	ALLOMYRINA	DICHOTOMUS	10
COLEOPTERA	SCARABAEIDAE	XYLOTROPES	DICHOTOMUS	(SEE ALLOMYRINA DICHOTOMUS)
LEPIDOPTERA	NYMPHALIDAE	MELITAEA	DIDYMA	12
LEPIDOPTERA	PYRALIDAE	NACOLEIA	DIEMENALIS	9
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	DIFFERENTIALIS	4 19
HYMENOPTERA	TENTHREDINIDAE	PIKONEMA	DIMMOCKII	12
LEPIDOPTERA	TORTRICIDAE	ZEIRAPHERA	DINIANA	9 12 16 19
LEPIDOPTERA	PYRALIDAE	BOTYODES	DINIASALIS	(SEE PYRAUSTA DINIASALIS)
LEPIDOPTERA	PYRALIDAE	PYRAUSTA	DINIASALIS	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	DISPAR	5 6 10 12 13 15 16 17 19
LEPIDOPTERA	LYMANTRIIDAE	OCNERIA	DISPAR	(SEE LYMANTRIA DISPAR)
LEPIDOPTERA	LYMANTRIIDAE	PORTHETRIA	DISPAR	(SEE LYMANTRIA DISPAR)
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	DISPAR JAPONICA	5 12
LEPIDOPTERA	LYMANTRIIDAE	PORTHETRIA	DISPAR JAPONICA	(SEE LYMANTRIA DISPAR JAPONICA)
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	DISSOLUTA	12
LEPIDOPTERA	LYMANTRIIDAE	OCNERIA	DISSOLUTA	(SEE LYMANTRIA DISSOLUTA)
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	DISSTRIA	5 12 16
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	DIVERSANA	12 19
LEPIDOPTERA	GEOMETRIDAE	CARIPETA	DIVISATA	12
LEPIDOPTERA	TORTRICIDAE	MEROPHYAS	DIVULSANA	12
DIPTERA	MUSCIDAE	MUSCA	DOMESTICA	3 13

ORDER	FAMILY	GENUS	SPECIES	DISEASES
ORTHOPTERA	GRYLLIDAE	ACHETA	DOMESTICUS	6 13 17
LEPIDOPTERA	ARCTIIDAE	PANAXIA	DOMINULA	5 12
DIPTERA	CULICIDAE	AEDES	DORSALIS	6 10 13
ODONATA	LIBELLULIDAE	LEUCORRHINIA	DUBIA	13
LEPIDOPTERA	TORTRICIDAE	RHYACIONIA	DUPLANA	9 12
LEPIDOPTERA	TORTRICIDAE	SCIAPHILA	DUPLEX	9
DIPTERA	SIMULIIDAE	SIMULIUM	EARLEI	10
HYMENOPTERA	BRACONIDAE	HYPOMICROGASTER	ECDYTOLOPHAE	13
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	EGLANTERINA	9 12 16
LEPIDOPTERA	SATURNIIDAE	PSEUDOHAZIS	EGLANTERINA	(SEE HEMILEUCA EGLANTERINA)
LEPIDOPTERA	LIMACODIDAE	EUPROSTERNA	ELEASA	17
LEPIDOPTERA	PIERIDAE	COLIAS	ELECTO	12 16
LEPIDOPTERA	NOCTUIDAE	ANOMOGYNA	ELIMATA	12
LEPIDOPTERA	GEOMETRIDAE	CROCALLIS	ELINGUARIA	5
ORTHOPTERA	ACRIDIDAE	AULOCARA	ELLIOTTI	4
LEPIDOPTERA	SPHINGIDAE	ERINNYIS	ELLO	12
LEPIDOPTERA	SPHINGIDAE	DEILEPHILA	ELPENOR	5 12 16
LEPIDOPTERA	SPHINGIDAE	PERGESA	ELPENOR	(SEE DEILEPHILA ELPENOR)
LEPIDOPTERA	LIMACODIDAE	BARIA	ELSA	17
LEPIDOPTERA	PYRALIDAE	EPHESTIA	ELUTELLA	12
LEPIDOPTERA	NOCTUIDAE	ORAESIA	EMARGINATA	5 12
LEPIDOPTERA	NOCTUIDAE	NEPHELODES	EMMEDONIA	9 12 16
DIPTERA	CULICIDAE	AEDES	EPACTIUS	12
LEPIDOPTERA	PSYCHIDAE	THYRIDOPTERYX	EPHEMERAEFORMIS	12 17
DIPTERA	SYRPHIDAE	MERODON	EQUESTRIS	13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ERECTA	13
HYMENOPTERA	TENTHREDINIDAE	PRISTIPHORA	ERICHSONII	12 16
LEPIDOPTERA	NOCTUIDAE	CHRYSODEIXIS	ERIOSOMA	5 12 13
DIPTERA	CULICIDAE	CULEX	ERRATICUS	5
HYMENOPTERA	PAMPHILIIDAE	ACANTHOLYDA	ERYTHROCEPHALA	12
LEPIDOPTERA	SPHINGIDAE	HIPPOTION	ESON	12
LEPIDOPTERA	NOCTUIDAE	CATABENA	ESULA	12 16
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	EUCALYPTI	5 10 13 15 17
LEPIDOPTERA	SPHINGIDAE	CELERIO	EUPHORBIAE	(SEE HYLES EUPHORBIAE)
LEPIDOPTERA	SPHINGIDAE	DEILEPHILA	EUPHORBIAE	(SEE HYLES EUPHORBIAE)
LEPIDOPTERA	SPHINGIDAE	HYLES	EUPHORBIAE	5 12 16
LEPIDOPTERA	PIERIDAE	COLIAS	EURYTHEME	5 12
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	EVONYMELLA	12
LEPIDOPTERA	NOCTUIDAE	PERSECTANIA	EWINGII	9 13 15
LEPIDOPTERA	NOCTUIDAE	ORAESIA	EXCAVATA	5
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	EXCITANS	12
LEPIDOPTERA	NOCTUIDAE	AGROTIS	EXCLAMATIONIS	9 12
DIPTERA	CULICIDAE	AEDES	EXCRUCIANS	10
LEPIDOPTERA	NOTODONTIDAE	NEOPHEOSIA	EXCURVATA	12
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	EXEMPTA	5 12 17
LEPIDOPTERA	NOCTUIDAE	LAPHYGMA	EXIGUA	(SEE SPODOPTERA EXIGUA)
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	EXIGUA	5 9 12
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	EXIGUAE	13 17
ISOPTERA	TERMITIDAE	NASUTITERMES	EXITIOSUS	13 15 17
LEPIDOPTERA	LIMACODIDAE	CASPHALIA	EXTRANEAE	6
HYMENOPTERA	BRACONIDAE	PROTOMICROPLITIS	FACETOSA	13
LEPIDOPTERA	GEOMETRIDAE	OPEROPHTERA	FAGATA	5
LEPIDOPTERA	OECOPHORIDAE	CHIMBAE	FAGELLA	(SEE DIURNEA FAGELLA)
LEPIDOPTERA	OECOPHORIDAE	DIURNEA	FAGELLA	16
LEPIDOPTERA	NOCTUIDAE	ANAGRAPHA	FALCIFERA	12
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	FASCIATA	5 9 19
DIPTERA	DROSOPHILIDAE	DROSOPHILA	FASCIATA	(SEE DROSOPHILA MELANOGASTER)
LEPIDOPTERA	LIMACODIDAE	IRAGOIDES	FASCIATA	12
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	FASCIPENNIS	9
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	FEMURRUBRUM	4
LEPIDOPTERA	NOCTUIDAE	ACTEBIA	FENNICA	12
DIPTERA	CULICIDAE	PSOROPHORA	FEROX	5 10 12
COLEOPTERA	CERAMBYCIDAE	PLOCAEDERUS	FERRUGINEUS	11
HYMENOPTERA	APIIDAE	BOMBUS	FERVIDUS	19
LEPIDOPTERA	PYRALIDAE	CADRA	FIGULILELLA	9 12
LEPIDOPTERA	GEOMETRIDAE	NEMATOCAMPA	FILAMENTARIA	9

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	LAMPRA	FIMBRIATA	5
LEPIDOPTERA	GEOMETRIDAE	LAMBDA	FISCELLARIA	12 16
LEPIDOPTERA	GEOMETRIDAE	LAMBDA	FISCELLARIA LUGUBROSA	9 12 16
LEPIDOPTERA	GEOMETRIDAE	LAMBDA	FISCELLARIA SOMNIARIA	9 12 16
LEPIDOPTERA	ZYGAENIDAE	PHAUDA	FLAMMANS	12
LEPIDOPTERA	NOCTUIDAE	PANOLIS	FLAMMEA	12 16
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	FLAMMEOLUS	10
LEPIDOPTERA	NOCTUIDAE	ANOMIS	FLAVA	12
LEPIDOPTERA	NOCTUIDAE	COSMOPHILA	FLAVA	(SEE ANOMIS FLAVA)
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	FLAVA	10 12
DIPTERA	CULICIDAE	AEDES	FLAVESCENS	10 19
LEPIDOPTERA	LIMACODIDAE	CNIDOCAMPA	FLAVESCENS	9 12
LEPIDOPTERA	NOTODONTIDAE	PHALERA	FLAVESCENS	12
HYMENOPTERA	ICHNEUMONIDAE	CAMPOLETIS	FLAVICINCTA	13
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	FLAVINATA	12
HYMENOPTERA	BRACONIDAE	APANTELES	FLAVIPES	13 17
HYMENOPTERA	BRACONIDAE	PHANEROTOMA	FLAVITESTACEA	13 17
LEPIDOPTERA	HESPERIIDAE	POTANTHUS	FLAVUM	10
ISOPTERA	MACROTERMITIDAE	ODONTOTERMES	FORMOSANUS	13
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	FRAGILE	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	FRAGILE INCURVA	12
DIPTERA	CULICIDAE	ANOPHELES	FREEBORNI	5
LEPIDOPTERA	GEOMETRIDAE	NEPYTIA	FREEMANI	5 12
DIPTERA	COELOPIDAE	COELOPA	FRIGIDA	17
LEPIDOPTERA	NOCTUIDAE	LAPHYGMA	FRUGIPERDA	(SEE SPODOPTERA FRUGIPERDA)
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	FRUGIPERDA	5 9 10 11 12 13 16
LEPIDOPTERA	TORTRICIDAE	RHYACIONIA	FRUSTRANA	9
LEPIDOPTERA	NOCTUIDAE	AGROTIS	FUCOSA	(SEE AGROTIS SEGETUM)
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	FUGITIVUS FUGITIVUS	13
LEPIDOPTERA	NOTODONTIDAE	PYGAERA	FULGURITA	12
ORTHOPTERA	BLATTIDAE	PERIPLANETA	FULIGINOSA	13
LEPIDOPTERA	ARCTIIDAE	PHRAGMATOBIA	FULIGINOSA	5 9 16
DIPTERA	CULICIDAE	AEDES	FULVUS PALLENS	10
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	FUMIDA FUMIDA	5 12
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	FUMIFERANA	5 9 10 12 13 19
HYMENOPTERA	BRACONIDAE	APANTELES	FUMIFERANAE	13 17
DIPTERA	DROSOPHILIDAE	DROSOPHILA	FUNEBRIS	3
LEPIDOPTERA	ZYGAENIDAE	ARTONA	FUNERALIS	9 10
LEPIDOPTERA	NOCTUIDAE	DRYOBOTA	FURVA	9 12
THYSANOPTERA	THRIPIDAE	FRANKLINIELLA	FUSCA	17
LEPIDOPTERA	LIMACODIDAE	SIBINE	FUSCA	6
DIPTERA	MUSCIDAE	GLOSSINA	FUSCIPES FUSCIPES	17
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	FUSCOCUPREANUS	19
LEPIDOPTERA	SPHINGIDAE	CELERIO	GALII	(SEE HYLES GALLII)
LEPIDOPTERA	SPHINGIDAE	HYLES	GALLII	12 16
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	GAMMA	5 12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	GAMMA	(SEE AUTOGRAPHA GAMMA)
LEPIDOPTERA	TORTRICIDAE	APHANIA	GEMINATA	10
HYMENOPTERA	FORMICIDAE	SOLENOPTIS	GEMINATA	17
LEPIDOPTERA	NOCTUIDAE	ANTICARSIA	GEMMATALIS	12 16
HYMENOPTERA	TENTHREDINIDAE	PRISTIPHORA	GENICULATA	12
DIPTERA	CULICIDAE	AEDES	GENICULATUS	6
LEPIDOPTERA	GRACILLARIIDAE	PARECTOPA	GEOMETROPIS	10
DIPTERA	DROSOPHILIDAE	DROSOPHILA	GIBBEROSA	3
LEPIDOPTERA	NOTODONTIDAE	NADATA	GIBBOSA	12
HYMENOPTERA	SIRICIDAE	UROCERUS	GIGAS GIGAS	5
LEPIDOPTERA	NOCTUIDAE	AMATHES	GLAREOSA	(SEE PARADIARSIA GLAREOSA)
LEPIDOPTERA	NOCTUIDAE	PARADIARSIA	GLAREOSA	5
LEPIDOPTERA	ARCTIIDAE	ARDICES	GLATIGNYI	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	GLAUCINOPTERA	12
LEPIDOPTERA	ZYGAENIDAE	PIDORUS	GLAUCOPIS ATRATUS	10
ACARI	PHTHIRACARIDAE	PHTHIRACARUS	GLOBOSUS	17
HYMENOPTERA	BRACONIDAE	APANTELES	GLOMERATUS	13 17
LEPIDOPTERA	TORTRICIDAE	ACLERIS	GLOVERANA	12
LEPIDOPTERA	AGARISTIDAE	PHALAEONIDES	GLYCINAE	9 13
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	GONOSTIGMA	12



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	BELLURA	GORTYNOIDES	12
LEPIDOPTERA	GELECHIIDAE	PECTINOPHORA	GOSSYPIELLA	5 12
LEPIDOPTERA	SATURNIIDAE	DIRPHIA	GRAGATUS	12
LEPIDOPTERA	NOCTUIDAE	CERAPTERYX	GRAMINIS	12 16
LEPIDOPTERA	NOCTUIDAE	CHARAEAS	GRAMINIS	(SEE CERAPTERYX GRAMINIS)
HEMIPTERA	APHIDIDAE	SCHIZAPHIS	GRAMINUM	13
LEPIDOPTERA	PYRALIDAE	DIATRAEA	GRANDIOSELLA	12
COLEOPTERA	CURCULIONIDAE	ANTHONOMUS	CRANDIS	10 12
LEPIDOPTERA	TORTRICIDAE	EUCOSMA	GRISEANA	(SEE ZEIRAPHERA DINIANA)
LEPIDOPTERA	PYRALIDAE	ACHROEA	GRISELLA	(SEE ACHROIA GRISELLA)
LEPIDOPTERA	PYRALIDAE	ACHROIA	GRISELLA	12
LEPIDOPTERA	GEOMETRIDAE	ABRAXAS	GROSSULARIATA	5 12
LEPIDOPTERA	HESPERIIDAE	PARNARA	GUTTATA	10 12
LEPIDOPTERA	NOTODONTIDAE	HETEROCAMPA	GUTTIVITTA	16
LEPIDOPTERA	SPHINGIDAE	CELERIO	HARMUTHI	16
LEPIDOPTERA	GEOMETRIDAE	EULYPE	HASTATA	(SEE RHEUMAPTERA HASTATA)
LEPIDOPTERA	GEOMETRIDAE	RHEUMAPTERA	HASTATA	9
LEPIDOPTERA	SATURNIIDAE	ANTHERAEA	HELENA	13
LEPIDOPTERA	NOCTUIDAE	AGROCHOLA	HELVOLA	5
LEPIDOPTERA	NOCTUIDAE	ANCHOSCELIS	HELVOLA	(SEE AGROCHOLA HELVOLA)
LEPIDOPTERA	TORTRICIDAE	PANDEMIS	HEPARANA	12
HYMENOPTERA	DIPRIONIDAE	DIPRION	HERCYNIAE	12
HYMENOPTERA	DIPRIONIDAE	GILPINIA	HERCYNIAE	(SEE DIPRION HERCYNIAE)
LEPIDOPTERA	NOTODONTIDAE	CERURA	HERMELINA	12 16
THYSANURA	PRAEMACHILIDAE	DILTA	HIBERNICA	12
LEPIDOPTERA	NOCTUIDAE	ORTHOSIA	HIBISCI	12
COLEOPTERA	SCARABAEIDAE	MELOLONTHA	HIPPOCASTANI	20
LEPIDOPTERA	GEOMETRIDAE	BISTON	HIRTARIA	12
LEPIDOPTERA	GEOMETRIDAE	BISTON	HISPIDARIA	12
DIPTERA	SCIARIDAE	RHYNCHOSCIARA	HOLLAENDERI	12
DIPTERA	CHIRONOMIDAE	GOELDICHIRONOMUS	HOLOPRASINUS	5 17 19
DIPTERA	CULICIDAE	PSOROPHORA	HORRIDA	10
COLEOPTERA	SCARABAEIDAE	PHYLLOPERTHA	HORTICOLA	19
HYMENOPTERA	APIDAE	BOMBUS	HORTORUM	1
DIPTERA	DROSOPHILIDAE	DROSOPHILA	HYDEI	3 13
LEPIDOPTERA	SPHINGIDAE	CEPHNODES	HYLAS	10
LEPIDOPTERA	NYMPHALIDAE	ARGYREUS	HYPERBIUS	10
LEPIDOPTERA	GEOMETRIDAE	ANTHELLIA	HYPERBOREA	12
HYMENOPTERA	BRACONIDAE	APANTELES	HYPHANTRIAE	13
HYMENOPTERA	PAMPHILIIDAE	LYDA	HYPOTROPHICA	(SEE CEPHALCIA ABIETIS)
LEPIDOPTERA	ARCTIIDAE	ECPANTHERIA	ICASIA	9 12
LEPIDOPTERA	TORTRICIDAE	PLATYNOTA	IDAEUSALIS	5 12
LEPIDOPTERA	PSYCHIDAE	CLANIA	IGNOBILIS	13
LEPIDOPTERA	GEOMETRIDAE	MELANOLOPHIA	IMITATA	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	IMMIGRANS	3 13
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	IMPARILIS	(SEE SPILOSOMA LUBRICIPEDA)
HYMENOPTERA	APIDAE	BOMBUS	IMPATIENS	19
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	INCERTA	12
LEPIDOPTERA	NOCTUIDAE	ORTHOSIA	INCERTA	12
LEPIDOPTERA	PYRALIDAE	SCIRPOPHAGA	INCERTULAS	12
LEPIDOPTERA	NOCTUIDAE	PSEUDOPUSIA	INCLUDENS	6 12 13 17
LEPIDOPTERA	SPHINGIDAE	PSILOGRAMMA	INCRETA	10
LEPIDOPTERA	PYRALIDAE	DIAPHANIA	INDICA	(SEE MARGARONIA INDICA)
LEPIDOPTERA	PYRALIDAE	MARGARONIA	INDICA	10
LEPIDOPTERA	ZYGAENIDAE	AGLAOPE	INFAUSTA	5
LEPIDOPTERA	NOCTUIDAE	SESAMIA	INFERENS	12
LEPIDOPTERA	PYRALIDAE	NAGIA	INFERIOR	10
HYMENOPTERA	ICHNEUMONIDAE	CASINARIA	INFESTA	13
HEMIPTERA	REDUVIIDAE	TRIATOMA	INFESTANS	17
LEPIDOPTERA	PYRALIDAE	CHILO	INFUSCATELLUS	9
DIPTERA	CULICIDAE	CULISETA	INORNATA	5 10 13
LEPIDOPTERA	NOCTUIDAE	EARIAS	INSULANA	5 12 17
LEPIDOPTERA	PYRALIDAE	PLODIA	INTERPUNCTELLA	9 12
LEPIDOPTERA	SATURNIIDAE	AUTOMERIS	IO	5
LEPIDOPTERA	NYMPHALIDAE	INACHIS	IO	5 10 12 16
LEPIDOPTERA	NYMPHALIDAE	NYMPHALIS	IO	(SEE INACHIS IO)

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NYMPHALIDAE	VANESSA	IO	(SEE INACHIS IO)
LEPIDOPTERA	NOCTUIDAE	AGROTIS	IPSILON	5 9 12
LEPIDOPTERA	GEOMETRIDAE	HYDRIDOMENA	IRATA	12
LEPIDOPTERA	SATURNIIDAE	PSEUDOBUNAEA	IRIUS	17
HYMENOPTERA	TENTHREDINIDAE	TRICHOICAMPUS	IRREGULARIS	12
LEPIDOPTERA	ARCTIIDAE	ISIA	ISABELLA	5
LEPIDOPTERA	TORTRICIDAE	ARCHIPPUS	ISSHIKII	19
HYMENOPTERA	PAMPHILIIDAE	CEPHALCIA	ISSIKI	12
HYMENOPTERA	FORMICIDAE	IRIDOMYRMEX	ITOI	10
LEPIDOPTERA	ARCTIIDAE	HYPOCRITA	JACOBABAE	5 12 13
LEPIDOPTERA	ARCTIIDAE	TYRIA	JACOBABAE	(SEE HYPOCRITA JACOBABAE)
LEPIDOPTERA	NOCTUIDAE	FERALIA	JACOSA	12
LEPIDOPTERA	NOCTUIDAE	ACHAEA	JANATA	9 12
LEPIDOPTERA	PSYCHIDAE	CRYPTOTHELEA	JAPONICA	(SEE CRYPTOTHELEA VARIEGATA)
LEPIDOPTERA	SATURNIIDAE	DICTYOPLOCA	JAPONICA	5 10 12
LEPIDOPTERA	NYMPHALIDAE	HESTINA	JAPONICA	10
LEPIDOPTERA	PAPILIONIDAE	LUEHDORFIA	JAPONICA	12
ORTHOPTERA	BLATTIDAE	PERIPLANETA	JAPONICA	13
LEPIDOPTERA	SPHINGIDAE	THERETRA	JAPONICA	12
LEPIDOPTERA	NYMPHALIDAE	CHARAXES	JASIUS	16
LEPIDOPTERA	GEOMETRIDAE	SYNAXIS	JUBARARIA	12
LEPIDOPTERA	GEOMETRIDAE	THERA	JUNIPERATA	5
LEPIDOPTERA	PSYCHIDAE	ACANTHOPSYCHE	JUNODI	(SEE CRYPTOTHELEA JUNODI)
LEPIDOPTERA	PSYCHIDAE	CRYPTOTHELEA	JUNODI	12
LEPIDOPTERA	PSYCHIDAE	KOTOCALIA	JUNODI	(SEE CRYPTOTHELEA JUNODI)
HYMENOPTERA	SIRICIDAE	SIREX	JUVENCUS	5
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	KARGHALICA	12
LEPIDOPTERA	SPHINGIDAE	CELERIO	KINDERVATERI	16
LEPIDOPTERA	PSYCHIDAE	OIKETYCUS	KIRBYI	5
LEPIDOPTERA	PYRALIDAE	ANAGASTA	KUEHNIELLA	12
LEPIDOPTERA	PYRALIDAE	EPHESTIA	KUEHNIELLA	(SEE ANAGASTA KUEHNIELLA)
LEPIDOPTERA	DREPANIDAE	DREPANA	LACERTINARIA	5
ISOPTERA	RHINOTERMIDAE	COPTOTERMES	LACTEUS	17
LEPIDOPTERA	ARCTIIDAE	AMSACTA	LACTINEA	9 12
ACARI	ARGASIDAE	ORNITHODOROS	LAHORENSIS	17
LEPIDOPTERA	TORTRICIDAE	PANDEMIS	LAMPROSANA	12
LEPIDOPTERA	LASIOCAMPIDAE	ERIOGASTER	LANESTRIS	5
COLEOPTERA	DERMESTIDAE	DERMESTES	LARDARIUS	12 16
LEPIDOPTERA	COLEOPHORIDAE	COLEOPHORA	LARICELLA	12
LEPIDOPTERA	PYRALIDAE	CRYPTOBLABES	LARICIANA	12
HYMENOPTERA	PAMPHILIIDAE	CEPHALEIA	LARICIPHILA	(SEE CEPHALCIA ALPINA)
LEPIDOPTERA	NYMPHALIDAE	ARGYNNIS	LATHONIA	16
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	LATIFASCIA	12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	LATIPENNIS	12
LEPIDOPTERA	NOCTUIDAE	LITHOPHANE	LEAUTIERI	5
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	LECONTEI	12 16
LEPIDOPTERA	LIMACODIDAE	LATOIA	LEPIDA	(SEE PARASA LEPIDA)
LEPIDOPTERA	LIMACODIDAE	PARASA	LEPIDA	9 12 17
LEPIDOPTERA	PIERIDAE	COLIAS	LESBIA	12
LEPIDOPTERA	NOCTUIDAE	AEDIA	LEUCOMELAS	12
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	LEUCOSTIGMA	5 12 16 17
LEPIDOPTERA	TORTRICIDAE	ARGYROPOLOCE	LEUCOTRETA	(SEE CRYPTOPHLEBIA LEUCOTRETA)
LEPIDOPTERA	TORTRICIDAE	CRYPTOPHLEBIA	LEUCOTRETA	5 9
HYMENOPTERA	DIPRIONIDAE	DIPRION	LEUWANENSIS	12
LEPIDOPTERA	NYMPHALIDAE	ARASCHNIA	LEVANA	12
LEPIDOPTERA	NOCTUIDAE	SCOLIOPTERYX	LIBATRIX	5 12
LEPIDOPTERA	PYRALIDAE	ELASMOPALPUS	LIGNOSELLUS	19
LEPIDOPTERA	SPHINGIDAE	SPHINX	LIGUSTRI	5 12
LEPIDOPTERA	GEOMETRIDAE	NYCTOBIA	LIMITARIA NIGROANGULATA	12
LEPIDOPTERA	SPHINGIDAE	CELERIO	LINEATA	(SEE HYLES LINEATA)
LEPIDOPTERA	SPHINGIDAE	HYLES	LINEATA	12
LEPIDOPTERA	HESPERIIDAE	THYMELICUS	LINEOLA	12
COLEOPTERA	CERAMBYCIDAE	BATOCERA	LINEOLATA	12
HYMENOPTERA	BRACONIDAE	APANTELES	LIPARIDIS	13 17
LEPIDOPTERA	NOCTUIDAE	PRODENIA	LITOSIA	12
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	LITTORALIS	9 12 17

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	PRODENIA	LITURA	(SEE SPODOPTERA LITURA)
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	LITURA	5 9 10 12 16
LEPIDOPTERA	GEOMETRIDAE	SEMIOTHISA	LITURATA	5
DIPTERA	TIPULIDAE	TIPULA	LIVIDA	10
LEPIDOPTERA	LYMANTRIIDAE	CIFUNA	LOCUPLES	(SEE DASYCHIRA LOCUPLES)
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	LOCUPLES	12
LEPIDOPTERA	TORTRICIDAE	TORTRIX	LOEFLINGIANA	12 16
LEPIDOPTERA	ARCTIIDAE	OCNOGYNA	LOEWII	17
LEPIDOPTERA	TORTRICIDAE	ARCHIPS	LONGICELLANA	9
LEPIDOPTERA	GEOMETRIDAE	EUPITHECIA	LONGIPALPATA	12
LEPIDOPTERA	LIMACODIDAE	MICROLEON	LONGIPALPIS	10
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	LUBRICIPEDA	(SEE SPILOSOMA LUBRICIPEDA)
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	LUBRICIPEDA	5 10 12
COLEOPTERA	SCARABAEIDAE	PROAGOPERTHA	LUCIDULA	19
LEPIDOPTERA	NOCTUIDAE	EUPLEXIA	LUCIPARA	9
HYMENOPTERA	APIDAE	BOMBUS	LUCORUM	1 15
HYMENOPTERA	FORMICIDAE	FORMICA	LUGUBRIS	17
LEPIDOPTERA	SATURNIIDAE	ACTIAS	LUNA	5
LEPIDOPTERA	GEOMETRIDAE	SELENIA	LUNARIA	5
LEPIDOPTERA	LASIOCAMPIDAE	SELENEPHERA	LUNIGERA	12
LEPIDOPTERA	NOCTUIDAE	CALOPHASIA	LUNULA	5 12
LEPIDOPTERA	HEPIALIDAE	HEPIALUS	LUPULINUS	5
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	LURIDUS	19
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	LUTEA	5
LEPIDOPTERA	GEOMETRIDAE	OPISTHOGRAPTIS	LUTEOLATA	12
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	LUTESCENS	12
LEPIDOPTERA	NOCTUIDAE	APOROPHYLA	LUTULENTA	5
LEPIDOPTERA	NOCTUIDAE	APOROPHYLLA	LUTULENTA	(SEE APOROPHYLA LUTULENTA)
LEPIDOPTERA	NOCTUIDAE	AGROCHOLA	LYCHNIDIS	5
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	MACHAON	5
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	MACHAON HIPPOCRATES	10
LEPIDOPTERA	GELECHIDAE	BRACHMIA	MACROSCOPA	10
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MACROSPINA	3
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MACROSPINA LIMPIENSIS	3
LEPIDOPTERA	PLUTELLIDAE	PLUTELLA	MACULIPENNIS	(SEE PLUTELLA XYLOSTELLA)
ORTHOPTERA	BLABERIDAE	LEUCOPHAEA	MADERAE	17
LEPIDOPTERA	TORTRICIDAE	HOMONA	MAGNANIMA	5 9 12 19
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	MAIA	12 16
HEMIPTERA	APHIDIDAE	RHOPALOSIPHUM	MAIDIS	17
LEPIDOPTERA	NOCTUIDAE	APATELE	MAJOR	10
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MALERKOTLIANA	13
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	MALINELLUS	12
LEPIDOPTERA	BOMBYCIDAE	THEOPHILA	MANDARINA	5 12
COLEOPTERA	CURCULIONIDAE	CRYPTORHYNCHUS	MANGIFERAE	13
COLEOPTERA	CURCULIONIDAE	STERNOCHETUS	MANGIFERAE	(SEE CRYPTORHYNCHUS MANGIFERAE)
DIPTERA	BIBIONIDAE	BIBIO	MARCI	10
LEPIDOPTERA	NOCTUIDAE	PERIDROMA	MARGARITOSA	(SEE PERIDROMA SAUCIA)
LEPIDOPTERA	GEOMETRIDAE	BISTON	MARGINATA	12 16
ACARI	IXODIDAE	DERMACENTOR	MARGINATUS	17
HYMENOPTERA	BRACONIDAE	APANTELES	MARGINIVENTRIS	13 17
LEPIDOPTERA	HESPERIIDAE	PARNARA	MATHIAS	12
LEPIDOPTERA	HESPERIIDAE	PELOPIDA	MATHIAS	(SEE PARNARA MATHIAS)
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	MATHURA	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	MATHURA AURORA	5 12
LEPIDOPTERA	NOCTUIDAE	MANIA	MAURA	5
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	MAURITIA	12 16
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	MAURITIA ACRONYCTOIDES	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MAURITIANA	13
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	MAYUMIVORELLUS	10
HYMENOPTERA	VESPIDAE	DOLICHOVESPULA	MEDIA	15
LEPIDOPTERA	PYRALIDAE	CNAPHALOCROCIS	MEDINALIS	9 10
LEPIDOPTERA	COCYTIIDAE	EUCOCYTIS	MEEKI	13
LEPIDOPTERA	SATYRIDAE	DIRA	MEGERA	5
HEMIPTERA	REDUVIIDAE	PANSTRONGYLUS	MEGISTUS	17
HYMENOPTERA	HALICTIDAE	NOMIA	MELANDERI	17
DIPTERA	CULICIDAE	AEDES	MELANIMON	13



ORDER	FAMILY	GENUS	SPECIES	DISEASES
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MELANOASTER	3 13 15 17
HYMENOPTERA	BRACONIDAE	COTESIA	MELANOSCELA	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	MELANOSCELUS	(SEE COTESIA MELANOSCELA)
DIPTERA	CULICIDAE	CULISETA	MELANURA	5 10
LEPIDOPTERA	PIERIDAE	PIERIS	MELETE	10
HYMENOPTERA	APIIDAE	APIS	MELLIFERA	1 2 6 10 13 15 17 18 21 22
LEPIDOPTERA	PYRALIDAE	GALLERIA	MELLONELLA	5 6 10 12 13 15 16 17 19
COLEOPTERA	SCARABAEIDAE	MELOLONTA	MELOLONTA	6 19 20
LEPIDOPTERA	SATURNIIDAE	AUTOMERIS	MEMUSAE	5
LEPIDOPTERA	PIERIDAE	NEOPHASIA	MENAPIA	12
LEPIDOPTERA	BOMBYCIDAE	RONDITIA	MENCIANA	12
LEPIDOPTERA	ARCTIIDAE	CYCNA	MENDICA	(SEE DIAPHORA MENDICA)
LEPIDOPTERA	ARCTIIDAE	DIAPHORA	MENDICA	5 12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	MENDOSA	12
LEPIDOPTERA	LYMANTRIIDAE	OLENE	MENDOSA	(SEE DASYCHIRA MENDOSA)
LEPIDOPTERA	SPHINGIDAE	PSILOGRAMMA	MENEPHRON	9
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	MENTHASTRI	(SEE SPILOSOMA LUBRICIPEDA)
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	MERKELI	5
LEPIDOPTERA	NOCTUIDAE	EUXOA	MESSORIA	5 9 12
DIPTERA	SIMULIIDAE	SIMULIUM	METALLICUM	10
LEPIDOPTERA	NOCTUIDAE	PHLOGOPHORA	METICULOSA	5 12
NEUROPTERA	MYRMELEONTIDAE	HAGENOMYIA	MICANS	16
ACARI	IXODIDAE	BOOPHILUS	MICROPLUS	17
ORTHOPTERA	ACRIDIDAE	LOCUSTA	MIGRATORIA	17 19
LEPIDOPTERA	GELECHIIDAE	COLEOTECHNITES	MILLERI	9
LEPIDOPTERA	GELECHIIDAE	RECURVARIA	MILLERI	(SEE COLEOTECHNITES MILLERI)
DIPTERA	SCIARIDAE	RHYNCHOSCIARA	MILLERI	12
LEPIDOPTERA	LIMACODIDAE	HYPHORMA	MINAX	12
ACARI	EUPHTHRACARIDAE	MICROTITIA	MINIMA	17
LEPIDOPTERA	PSYCHIDAE	MAHASENA	MINUSCULA	12
COLEOPTERA	CHRYSOMELIDAE	COELAENOMENODERA	MINUTA	13
LEPIDOPTERA	GEOMETRIDAE	CALOSPILOS	MIRANDA	10
LEPIDOPTERA	PYRALIDAE	SYBRIDA	MISAKIENSIS	10
DIPTERA	SIMULIIDAE	PROSIMULIUM	MIXTUM	5
DIPTERA	SIMULIIDAE	PROSIMULIUM	MIXTUM FUSCUM	5
LEPIDOPTERA	GEOMETRIDAE	PERO	MIZON	12
LEPIDOPTERA	SPHINGIDAE	PACHYSPHINX	MODESTA	5
LEPIDOPTERA	GELECHIIDAE	APROAEREMA	MODICELLA	12
LEPIDOPTERA	TORTRICIDAE	GRAPHOLITHA	MOLESTA	9
DIPTERA	CULICIDAE	CULEX	MOLESTUS	(SEE CULEX PIPIENS MOLESTUS)
COLEOPTERA	TENEBRIONIDAE	TENEBRIO	MOLITOR	10 17
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	MONACHA	5 12 16
LEPIDOPTERA	LYMANTRIIDAE	OCNERIA	MONACHA	(SEE LYMANTRIA MONACHA)
COLEOPTERA	SCARABAEIDAE	ORYCTES	MONOCEROS	11 20
LEPIDOPTERA	NOCTUIDAE	DRYOBOTODES	MONOCHROMA	12
HEMIPTERA	CICADELLIDAE	COLLADONUS	MONTANUS	10
DIPTERA	DROSOPHILIDAE	DROSOPHILA	MONTIUM	13
LEPIDOPTERA	ARCTIIDAE	AMSACTA	MOOREI	12 19
COLEOPTERA	SCARABAEIDAE	RHOPAEA	MORBILLOSA	(SEE ANTITROGUS MORBILLOSUS)
COLEOPTERA	SCARABAEIDAE	ANTITROGUS	MORBILLOSUS	19
LEPIDOPTERA	BOMBYCIDAE	BOMBYX	MORI	5 6 7 8 10 12 13 14 19
LEPIDOPTERA	NOCTUIDAE	HYDRILLODES	MOROSA	10
DIPTERA	CULICIDAE	CULISETA	MORSITANS	10
DIPTERA	MUSCIDAE	GLOSSINA	MORSITANS CENTRALIS	17
DIPTERA	MUSCIDAE	GLOSSINA	MORSITANS MORSITANS	17
DIPTERA	MUSCIDAE	GLOSSINA	MORSITANS ORIENTALIS	17
DIPTERA	CECIDOMYIIDAE	SITODIPLOSIS	MOSELLANA	16
ACARI	ARGASIDAE	ORNITHODOROS	MOUBATA	17
ACARI	TETRANYCHIDAE	TETRANYCHUS	MULTISETIS	17
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	MUNDUS	16
LEPIDOPTERA	TORTRICIDAE	CACOECIA	MURINANA	(SEE CHORISTONEURA MURINANA)
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	MURINANA	9 12 16
COLEOPTERA	DERMESTIDAE	ANTHRENUS	MUSEORUM	12 16
DIPTERA	SIMULIIDAE	CNEPHIA	MUTATA	5
DIPTERA	SIMULIIDAE	STEGOPTERNA	MUTATA	(SEE CNEPHIA MUTATA)
LEPIDOPTERA	SATURNIIDAE	ANTHRAEA	MYLITTA	(SEE ANTHRAEA PAPHIA MYLITTA)

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	HADA	NANA	5
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	NANULUS	16
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	NANULUS CONTORTAE	12
LEPIDOPTERA	PIERIDAE	PIERIS	NAPI	9
LEPIDOPTERA	LIMACODIDAE	NATADA	NARARIA	9
LEPIDOPTERA	LIMACODIDAE	SUSICA	NARARIA	(SEE NATADA NARARIA)
LEPIDOPTERA	NOCTUIDAE	ELYGMA	NARCISSUS	10
COLEOPTERA	SCARABAEIDAE	ORYCTES	NASICORNIS	11 20
DIPTERA	DROSOPHILIDAE	DROSOPHILA	NASUTA	13
COLEOPTERA	GYRINIDAE	GYRINUS	NATATOR	13
ORTHOPTERA	ACRIDIDAE	PHOETALIOTES	NEBRASCENSIS	19
DIPTERA	DROSOPHILIDAE	DROSOPHILA	NEBULOSA	13
HYMENOPTERA	PAMPHILIIDAE	ACANTHOLYDA	NEMORALIS	16
LEPIDOPTERA	SPHINGIDAE	THERETRA	NESSUS	10
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	NEUSTRIA	5 12 16
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	NEUSTRIA TESTACEA	5 12 16
LEPIDOPTERA	NOCTUIDAE	TRICHOPLUSIA	NI	5 9 10 12 13
LEPIDOPTERA	TORTRICIDAE	CYDIA	NIGRICANA	9
LEPIDOPTERA	SATURNIIDAE	HYLESIA	NIGRICANS	12
HYMENOPTERA	BRACONIDAE	CARDIOCHILES	NIGRICEPS	13 17
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	NIGRISIGNA	12
DIPTERA	CULICIDAE	AEDES	NIGROMACULIS	12
HEMIPTERA	APHIDIDAE	PENTALONIA	NIGRONERVOSA	17
ORTHOPTERA	GRYLLIDAE	PTERONEMOBIUS	NIGROVUS	13
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	NINAYI	12 13
LEPIDOPTERA	CARPOSINIDAE	CARPOSINA	NIPONENSIS	9 12
HYMENOPTERA	DIPRIONIDAE	DIPRION	NIPPONICA	12
LEPIDOPTERA	LIMACODIDAE	SETORA	NITENS	13
LEPIDOPTERA	LASIOCAMPIDAE	LEBEDA	NOBILIS	12
HYMENOPTERA	SIRICIDAE	SIREX	NOCTILIO	5
LEPIDOPTERA	NOCTUIDAE	SESAMIA	NONAGRIOIDES	9
LEPIDOPTERA	NOCTUIDAE	RACIPLUSIA	NU	12 16
LEPIDOPTERA	PYRALIDAE	OSTRINIA	NUBILALIS	12 17
LEPIDOPTERA	GEOMETRIDAE	HYDRIOMENA	NUBILOFASCIATA	12
LEPIDOPTERA	NOCTUIDAE	CATOCALA	NYMPHAEA	12
LEPIDOPTERA	NOCTUIDAE	CATOCALA	NYMPHAGOGA	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	OBFUSCATA	12
LEPIDOPTERA	LYMANTRIIDAE	PORTHETRIA	OBFUSCATA	(SEE LYMANTRIA OBFUSCATA)
LEPIDOPTERA	ARCTIIDAE	DIACRSIA	OBLIQUA	9 12
LEPIDOPTERA	GEOMETRIDAE	ECTROPIS	OBLIQUA	9 12
LEPIDOPTERA	NOCTUIDAE	CHLORIDEA	OBSOLETA	(SEE HELIOTHIS ARMIGERA)
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	OBTECTUS	12
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	OCCIDENTALIS	9 12
ORTHOPTERA	GRYLLIDAE	TELEOGRYLLUS	OCEANICUS	13 15
LEPIDOPTERA	TORTRICIDAE	SPILONOTA	OCELLANA	12
LEPIDOPTERA	SPHINGIDAE	SMERINTHUS	OCELLATA	5 12 16
LEPIDOPTERA	SPHINGIDAE	SMERINTHUS	OCELLATA ATLANTICUS	12 16
LEPIDOPTERA	NOCTUIDAE	EUXOA	OCHROGASTER	5 9 12 16
LEPIDOPTERA	LYMANTRIIDAE	IVELA	OCHROPODA	12
LEPIDOPTERA	PYRALIDAE	NACOLEIA	OCTOSEMA	12
DIPTERA	CERATOPOGONIDAE	CULICOIDES	ODIBILIS	10
LEPIDOPTERA	SPHINGIDAE	THERETRA	OLDENLANDIAE	10
LEPIDOPTERA	YPONOMEUTIDAE	PRAYS	OLEELLUS	16
LEPIDOPTERA	NOCTUIDAE	DIATARAXIA	OLERACEA	(SEE LACANOBIA OLERACEA)
LEPIDOPTERA	NOCTUIDAE	LACANOBIA	OLERACEA	5 9 12
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	OLERACEA	(SEE LACANOBIA OLERACEA)
DIPTERA	TIPULIDAE	TIPULA	OLERACEA	10
HYMENOPTERA	TENTHREDINIDAE	NEMATUS	OLFACIENS	12
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	OLIVIAE	9 12 16
LEPIDOPTERA	NOCTUIDAE	DICYCLA	OO	12
LEPIDOPTERA	MEGALOPYGIDAE	MEGALOPYGE	OPERCULARIS	9
LEPIDOPTERA	GELECHIIDAE	GNORIMOSCHEMA	OPERCULELLA	(SEE PHTHORIMAEA OPERCULELLA)
LEPIDOPTERA	GELECHIIDAE	PHTHORIMAEA	OPERCULELLA	9 12
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	ORANA	5 9 12 19
LEPIDOPTERA	NOCTUIDAE	DIACHRYSLA	ORICALCEA	12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	ORICALCEA	(SEE DIACHRYSLA ORICALCEA)

ORDER	FAMILY	GENUS	SPECIES	DISEASES
DIPTERA	SIMULIIDAE	ODAGMIA	ORNATA	10
DIPTERA	SIMULIIDAE	SIMULIUM	ORNATUM	10
HYMENOPTERA	BRACONIDAE	APANTELES	ORNIGIS	13 17
LEPIDOPTERA	NOCTUIDAE	PRODENIA	ORNITHOGALLI	(SEE SPODOPTERA ORNITHOGALLI)
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	ORNITHOGALLI	12 16
LEPIDOPTERA	LASIOCAMPIDAE	PACHYPASA	OTUS	12
LEPIDOPTERA	NOCTUIDAE	RACHIPLUSIA	OU	12
LEPIDOPTERA	NOCTUIDAE	ALETIA	OXYGALA LUTEOPALLENS	12
LEPIDOPTERA	TORTRICIDAE	ARCHIPPUS	PACKARDIANUS	9
LEPIDOPTERA	YPONOMEUTIDAE	YPONOMEUTA	PADELLA	12
HEMIPTERA	APHIDIDAE	RHOPALOSIPHUM	PADI	13 17
HYMENOPTERA	BRACONIDAE	APANTELES	PALEACRITAE	13 17
HYMENOPTERA	DIPRIONIDAE	DIPRION	PALLIDA	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PALLIDIPENNIS	3
DIPTERA	MUSCIDAE	GLOSSINA	PALLIDIPE	17
LEPIDOPTERA	TORTRICIDAE	AMELIA	PALLORANA	9
LEPIDOPTERA	GEOMETRIDAE	SYNAXIS	PALLULATA	12
DIPTERA	TIPULIDAE	TIPULA	PALUDOSA	10 12 16
LEPIDOPTERA	SATURNIIDAE	COLORADIA	PANDORA	12 16
LEPIDOPTERA	GEOMETRIDAE	CULCULA	PANTERINARIA	12
LEPIDOPTERA	NYMPHALIDAE	ARGYNNIS	PAPHIA	12 16
LEPIDOPTERA	SATURNIIDAE	ANTHERAEA	PAPHIA MYLITTA	5 12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PARADOXA	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PAULISTORUM	13 17
LEPIDOPTERA	SATURNIIDAE	SATURNIA	PAVONIA MAJOR	(SEE SATURNIA PYRI)
DIPTERA	CULICIDAE	CULEX	PECCATOR	5 10
HYMENOPTERA	ARGIDAE	ARGE	PECTORALIS	9 12
LEPIDOPTERA	GEOMETRIDAE	PHIGALIA	PEDARIA	(SEE APOCHEIMA PILOSARIA)
LEPIDOPTERA	TINEIDAE	TINEA	PELLIONELLA	5 10 12
ACARI	CAMISIIDAE	PLATYNOTHRUS	PELTIFER	17
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PELTIGERA	12
HYMENOPTERA	APIDAE	BOMBUS	PENNSYLVANICUS	19
LEPIDOPTERA	NOCTUIDAE	ANADEVIDIA	PEPONIS	10 12
LEPIDOPTERA	NOCTUIDAE	PLUSIA	PEPONIS	(SEE ANADEVIDIA PEPONIS)
LEPIDOPTERA	NOCTUIDAE	PODIOPLUSIA	PEPONIS	(SEE ANADEVIDIA PEPONIS)
NEUROPTERA	CHRYSOPIDAE	CHRYSOPA	PERLA	5 12
LEPIDOPTERA	SESIIDAE	PARANTHRENE	PERNIX	10
LEPIDOPTERA	SATURNIIDAE	ANTHERAEA	PERNYI	5 12 13 16
HEMIPTERA	APHIDIDAE	MYZUS	PERSICAE	17
LEPIDOPTERA	TORTRICIDAE	CLEPSIS	PERSICANA	9
LEPIDOPTERA	NOCTUIDAE	MELANCHRA	PERSICARIAE	9
ACARI	ARGASIDAE	ARGAS	PERSICUS	17
ACARI	PHYTOSEIIDAE	PHYTOSEIULUS	PERSIMILIS	17
LEPIDOPTERA	TORTRICIDAE	SPARGANOTHIS	PETTITANA	12
LEPIDOPTERA	LYMANTRIIDAE	NYGMIA	PHAEORRHOEA	16
LEPIDOPTERA	GEOMETRIDAE	NEPYTTIA	PHANTASMARIA	12
LEPIDOPTERA	TORTRICIDAE	CYDIA	PHASEOLI	(SEE LATHRONYMPHA PHASEOLI)
LEPIDOPTERA	TORTRICIDAE	LATHRONYMPHA	PHASEOLI	9
LEPIDOPTERA	ARCTIIDAE	ALPHAEA	PHASMA	12
LEPIDOPTERA	SPHINGIDAE	CELERIO	PHILEUPHORBIAE	16
LEPIDOPTERA	PIERIDAE	COLIAS	PHILODICE	12 16
LEPIDOPTERA	LYCAENIDAE	LYCAENA	PHLAEAS	5 10
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PHLOXIPHAGA	12 16
LEPIDOPTERA	LYMANTRIIDAE	PANTANA	PHYLLOSTACHYSAE	12
LEPIDOPTERA	NOCTUIDAE	CERAMICA	PICTA	5 12
COLEOPTERA	BUPRESTIDAE	MELANOPHILA	PICTA	5 16
LEPIDOPTERA	GEOMETRIDAE	APOCHEIMA	PILOSARIA	12
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	PILOSULUS	13
LEPIDOPTERA	SPHINGIDAE	HYLOICUS	PINASTRI	5 12
LEPIDOPTERA	SPHINGIDAE	SPHINX	PINASTRI	(SEE HYLOICUS PINASTRI)
HYMENOPTERA	DIPRIONIDAE	DIPRION	PINDROWI	12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	PINI	5 12 16
HYMENOPTERA	DIPRIONIDAE	DIPRION	PINI	12
LEPIDOPTERA	GEOMETRIDAE	BUPALUS	PINIARIUS	5 12 16
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	PINUS	12
DIPTERA	CULICIDAE	CULEX	PIPIENS	3 5



ORDER	FAMILY	GENUS	SPECIES	DISEASES
DIPTERA	CULICIDAE	CULEX	PIPIENS FATIGANS	(SEE C. PIPIENS QUINQUEFASCIATUS)
DIPTERA	CULICIDAE	CULEX	PIPIENS MOLESTUS	6 19
DIPTERA	CULICIDAE	CULEX	PIPIENS PIPIENS	5 6
DIPTERA	CULICIDAE	CULEX	PIPIENS QUINQUEFASCIATUS	3 10 12
LEPIDOPTERA	NOCTUIDAE	CERAMICA	PISI	12
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	PISI	(SEE CERAMICA PISI)
LEPIDOPTERA	THAUMETOPOEIDAE	THAUMETOPOEA	PITYOCAMPA	5 9 12 13
LEPIDOPTERA	GEOMETRIDAE	ANAITIS	PLAGIATA	5 12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	PLAGIATA	12
LEPIDOPTERA	NOCTUIDAE	TIRACOLA	PLAGIATA	12
LEPIDOPTERA	AKCTIIDAE	PARASEMIA	PLANTAGINIS	5
COLEOPTERA	SCARABAEIDAE	PHYLLOPHAGA	PLEEI	19
LEPIDOPTERA	DANAIDAE	DANAU	PLEXIPPUS	5 16 17
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	PLUMOSUS	5 10
LEPIDOPTERA	LASIOCAMPIDAE	MALACOSOMA	PLUVIALE	9 12
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	PODALIRIUS	12
LEPIDOPTERA	LASIOCAMPIDAE	CONOMETA	PODOCARPI	13
LEPIDOPTERA	NYMPHALIDAE	NYMPHALIS	POLYCHLOROS	12 16
LEPIDOPTERA	NYMPHALIDAE	VANESSA	POLYCHLOROS	(SEE NYMPHALIS POLYCHLOROS)
LEPIDOPTERA	SATURNIIDAE	ANTHERAEA	POLYPHEMUS	5 12 16
HYMENOPTERA	DIPRIONIDAE	DIPRION	POLYTOMA	12
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	POLYXENES	12
LEPIDOPTERA	GEOMETRIDAE	ALSOPHILA	POMETARIA	5 9 12
LEPIDOPTERA	PIERIDAE	CATOPSILIA	POMONA	6 12
LEPIDOPTERA	TORTRICIDAE	CARPOCAPSA	POMONELLA	(SEE CYDIA POMONELLA)
LEPIDOPTERA	TORTRICIDAE	CYDIA	POMONELLA	9 12 16
LEPIDOPTERA	TORTRICIDAE	LASPEYRESIA	POMONELLA	(SEE CYDIA POMONELLA)
LEPIDOPTERA	SPHINGIDAE	LAOTHOE	POPULI	5 12
LEPIDOPTERA	GEOMETRIDAE	PROTOBOARMIA	PORCELARIA INDICATARIA	12
COLEOPTERA	SCARABAEIDAE	ANOPLOGNATHUS	POROSUS	19
LEPIDOPTERA	NOCTUIDAE	PANTHEA	PORTLANDIA	12
COLEOPTERA	CURCULIONIDAE	HYPERA	POSTICA	14
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	POSTICA	12
LEPIDOPTERA	LIMACODIDAE	SETORA	POSTORNATA	5
LEPIDOPTERA	LIMACODIDAE	THOSEA	POSTORNATA	(SEE SETORA POSTORNATA)
LEPIDOPTERA	TORTRICIDAE	EPIPHYAS	POSTVITTANA	12
LEPIDOPTERA	LASIOCAMPIDAE	COSMOTRICHE	POTATORIA	12
LEPIDOPTERA	NOCTUIDAE	PRODENIA	PRAEFICA	12
HYMENOPTERA	PAMPHILIIDAE	TENTHREDO	PRATENSIS	(SEE ACANTHOLYDA NEMORALIS)
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	PRATTI BANKSIANAE	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	PRATTI PRATTI	16
LEPIDOPTERA	NOCTUIDAE	AUTOGRAPHA	PRECATIONIS	12
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	PRIVATANA	(SEE ADOXOPHYES ORANA)
LEPIDOPTERA	THAUMETOPOEIDAE	THAUMETOPOEA	PROCESSIONEA	5 12
LEPIDOPTERA	NOCTUIDAE	NOCTUA	PRONUBA	5 12
LEPIDOPTERA	NOCTUIDAE	TRIPHAENA	PRONUBA	(SEE NOCTUA PRONUBA)
LEPIDOPTERA	NYMPHALIDAE	VANESSA	PRORSA	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PROSALTANS	3
LEPIDOPTERA	SPHINGIDAE	PROSERPINUS	PROSERPINA	16
HEMIPTERA	DELPHACIDAE	TAROPHAGUS	PROSERPINA	17
LEPIDOPTERA	NOCTUIDAE	DRYOBOTA	PROTEA	12
LEPIDOPTERA	HESPERIIDAE	URBANUS	PROTEUS	12
COLEOPTERA	SCARABAEIDAE	SERICESTHIS	PRUINOSA	10
LEPIDOPTERA	ZYGAEINIDAE	ILLIBERIS	PRUNI	10
LEPIDOPTERA	GEOMETRIDAE	HYDRIA	PRUNIVORATA	9
LEPIDOPTERA	SATURNIIDAE	SAMIA	PRYERI	5 10 12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	PSEUDABIETIS	10 12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	PSEUDOCONSPERSA	5 10 12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	PSEUDOBOBSCURA	3 17
DIPTERA	CULICIDAE	AEDES	PSEUDOSCUPELLARIS	17
LEPIDOPTERA	TORTRICIDAE	ZEIRAPHERA	PSEUDOTSUGANA	12
LEPIDOPTERA	LYMANTRIIDAE	HEMEROCAMPA	PSEUDOTSUGATA	(SEE ORGYIA PSEUDOTSUGATA)
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	PSEUDOTSUGATA	5 12 16
LEPIDOPTERA	PYRALIDAE	DIORYCTRIA	PSEUDOTSUGELLA	12
LEPIDOPTERA	ZYGAEINIDAE	ILLIBERIS	PSYCHINA	(SEE ILLIBERIS PRUNI)
LEPIDOPTERA	THYATIRIDAE	EUTHYATIRA	PUDENS	12

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	PUDIBUNDA	5 12 13 16
LEPIDOPTERA	GEOMETRIDAE	SEMIOTHISA	PUMILA	13
LEPIDOPTERA	ARCTIIDAE	SPILOSOMA	PUNCTARIA	5 10
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	PUNCTATUS	5 12 13
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	PUNCTATUS TEHCHANGENSIS	12
LEPIDOPTERA	PYRALIDAE	DICHOCROCIS	PUNCTIFERALIS	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	PUNCTIGERA	9 12
LEPIDOPTERA	ARCTIIDAE	DIACRISIA	PURPURATA	5 12
LEPIDOPTERA	ARCTIIDAE	RHYPARIA	PURPURATA	(SEE DIACRISIA PURPURATA)
LEPIDOPTERA	NOCTUIDAE	PAPAIPEMA	PURPURIFASCIA	9
ORTHOPTERA	MANTIDAE	HOLAPTILON	PUSILLULUM	17
LEPIDOPTERA	NOCTUIDAE	AXYLIA	PUTRIS	5
DIPTERA	CERATOPOGONIDAE	BEZZIA	PYGMAEA	10
LEPIDOPTERA	PYRALIDAE	DIAPHANIA	PYLOALIS	(SEE MARGARONIA PYLOALIS)
LEPIDOPTERA	PYRALIDAE	GLYPHODES	PYLOALIS	(SEE MARGARONIA PYLOALIS)
LEPIDOPTERA	PYRALIDAE	MARGARONIA	PYLOALIS	6 10
LEPIDOPTERA	SATURNIIDAE	ERIOGYNIA	PYRETORUM	12
LEPIDOPTERA	SATURNIIDAE	SATURNIA	PYRI	5 12 13 16
LEPIDOPTERA	SPHINGIDAE	MACROGLOSSUM	PYRRHOSTICTA	10
HYMENOPTERA	BRACONIDAE	ASCOGASTER	QUADRIDENTATA	13
DIPTERA	CULICIDAE	ANOPHELES	QUADRIMACULATUS	5 10 14
COLEOPTERA	CERAMBYCIDAE	STENYGRINUM	QUADRINOTATUM	(SEE STENODRYAS CLAVIGERA)
LEPIDOPTERA	ARCTIIDAE	CALLIMORPHA	QUADRIPUNCTARIA	(SEE EUPLAGIA QUADRIPUNCTARIA)
LEPIDOPTERA	ARCTIIDAE	EUPLAGIA	QUADRIPUNCTARIA	5 13
LEPIDOPTERA	GEOMETRIDAE	ENNOMOS	QUERCARIA	12
LEPIDOPTERA	LASIOCAMPIDAE	GASTROPACHA	QUERCIFOLIA	5 12
LEPIDOPTERA	LASIOCAMPIDAE	GASTROPACHA	QUERCIFOLIA CERRIDIFOLIA	5 10 12
LEPIDOPTERA	GEOMETRIDAE	ENNOMOS	QUERCINARIA	12
LEPIDOPTERA	LASIOCAMPIDAE	LASIOCAMPA	QUERCUS	5 12
LEPIDOPTERA	SPHINGIDAE	MANDUCA	QUINQUEMACULATA	9
LEPIDOPTERA	SPHINGIDAE	PROTOPARCE	QUINQUEMACULATA	(SEE MANDUCA QUINQUEMACULATA)
DIPTERA	CULICIDAE	ERETMAPODITES	QUINQUEVITTATUS	12
LEPIDOPTERA	TORTRICIDAE	GRISELDA	RADICANA	9
LEPIDOPTERA	PIERIDAE	ARTOGEIA	RAPAE	(SEE PIERIS RAPAE)
LEPIDOPTERA	PIERIDAE	PIERIS	RAPAE	5 6 9 12 13 16
LEPIDOPTERA	PIERIDAE	PIERIS	RAPAE CRUCIVORA	5 9 12
LEPIDOPTERA	LIMACODIDAE	THOSEA	RECTA	17
COLEOPTERA	LUCANIDAE	MACRODORCUS	RECTUS	10
DIPTERA	DROSOPHILIDAE	DROSOPHILA	REPLETA	3
LEPIDOPTERA	GEOMETRIDAE	CARECOMOTIS	REPULSARIA	10
DIPTERA	CULICIDAE	CULEX	RESTUANS	5 17
LEPIDOPTERA	TORTRICIDAE	ADOXOPHYES	RETICULANA	(SEE ADOXOPHYES ORANA)
LEPIDOPTERA	PIERIDAE	GONEPTERYX	RHAMNI	5
COLEOPTERA	SCARABAEIDAE	ORYCTES	RHINOCEROS	11
LEPIDOPTERA	GEOMETRIDAE	CLEORA	RIBEATA	(SEE DEILEPTENIA RIBEATA)
LEPIDOPTERA	GEOMETRIDAE	DEILEPTENIA	RIBEATA	12
LEPIDOPTERA	ARCTIIDAE	PERICALLIA	RICINI	9 12
LEPIDOPTERA	SATURNIIDAE	SAMIA	RICINI	5 7 12 13 16
DIPTERA	DROSOPHILIDAE	DROSOPHILA	ROBUSTA	3
LEPIDOPTERA	GEOMETRIDAE	BISTON	ROBUSTUM	12
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	ROSACEANA	12
ORTHOPTERA	BACILLIDAE	BACILLUS	ROSSII	13 17
HYMENOPTERA	MEGACHILIDAE	MEGACHILE	ROTUNDATA	2 5 13 17
HYMENOPTERA	BRACONIDAE	APANTELES	RUBECULA	13
LEPIDOPTERA	LASIOCAMPIDAE	MACROTHYLACIA	RUBI	12
DIPTERA	SIMULIIDAE	SIMULIUM	RUBICUNDULUM	(SEE SIMULIUM VIRGATUM)
LEPIDOPTERA	SPHINGIDAE	AMPELOPHAGA	RUBIGINOSA	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	RUBRESCENS	9
COLEOPTERA	LUCANIDAE	MACRODORCUS	RUBROFEMORATUS	10
HYMENOPTERA	APIDAE	BOMBUS	RUDERARIUS	1
HEMIPTERA	APHIDIDAE	RHOPALOSIPHUM	RUFIBRUNNEA	13
LEPIDOPTERA	LASIOCAMPIDAE	GONOMETA	RUFIBRUNNEA	5
HYMENOPTERA	TENTHREDINIDAE	MESONEURA	RUFONOTA	12
HYMENOPTERA	DIPRIONIDAE	LOPHYRUS	RUFUS	(SEE NEODIPRION SERTIFER)
LEPIDOPTERA	NOCTUIDAE	ANOMIS	SABULIFERA	12
LEPIDOPTERA	PYRALIDAE	WITLESIA	SABULOSELLA	10

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	PYRALIDAE	DIATRAEA	SACCHARALIS	6 9 12
LEPIDOPTERA	PYRALIDAE	CHILO	SACCHARIPHAGUS	5
LEPIDOPTERA	PYRALIDAE	CHILO	SACCHARIPHAGUS INDICUS	9
LEPIDOPTERA	LYMANTRIIDAE	LEUCOMA	SALICIS	5 12 16
LEPIDOPTERA	LYMANTRIIDAE	STILPNOTIA	SALICIS	(SEE LEUCOMA SALICIS)
DIPTERA	CULICIDAE	CULEX	SALINARIUS	5 10 12 17
LEPIDOPTERA	GEOMETRIDAE	OURAPTERYX	SAMBUCARIA	5
ORTHOPTERA	ACRIDIDAE	MELANOPLUS	SANGUINIPES	4 19
DIPTERA	CULICIDAE	URANOTAENIA	SAPPHIRINA	5 12 17
LEPIDOPTERA	PAPILIONIDAE	GRAPHIUM	SARPEDON	10
LEPIDOPTERA	NOCTUIDAE	EUPSILIA	SATELLITIA	9
LEPIDOPTERA	NYMPHALIDAE	POLYGONIA	SATYRUS	12
LEPIDOPTERA	NOCTUIDAE	PERIDROMA	SAUCIA	5 9 12 16
LEPIDOPTERA	NOCTUIDAE	PLATHYPENA	SCABRA	9 12
LEPIDOPTERA	NOCTUIDAE	EUXOA	SCANDENS	5 12
LEPIDOPTERA	LYMANTRIIDAE	PORTHESIA	SCINTILLANS	12
COLEOPTERA	SCOLYTIDAE	SCOLYTUS	SCOLYTUS	17
LEPIDOPTERA	SCYTHRIDAE	TETRALOPHA	SCORTEALIS	12 16
DIPTERA	CULICIDAE	AEDES	SCUTELLARIS	12
LEPIDOPTERA	GEOMETRIDAE	CLEORA	SECUNDARIA	17
LEPIDOPTERA	NOCTUIDAE	AGROTIS	SEGETUM	5 9 12
LEPIDOPTERA	NOCTUIDAE	SCOTIA	SEGETUM	(SEE AGROTIS SEGETUM)
LEPIDOPTERA	NOCTUIDAE	SYNGRAPHIA	SELECTA	12
LEPIDOPTERA	SATURNIIDAE	ACTIAS	SELENE	5 13
LEPIDOPTERA	SATURNIIDAE	ACTIAS	SELENE NINGPOANA	12
LEPIDOPTERA	LYMANTRIIDAE	DASYCHIRA	SELENITICA	16
LEPIDOPTERA	SATURNIIDAE	ANISOTA	SENIATORIA	12 16
LEPIDOPTERA	NOCTUIDAE	LEUCANIA	SEPARATA	(SEE PSEUDALETIA SEPARATA)
LEPIDOPTERA	NOCTUIDAE	MYTHIMNA	SEPARATA	(SEE PSEUDALETIA SEPARATA)
LEPIDOPTERA	NOCTUIDAE	PSEUDALETIA	SEPARATA	9 12 13 19
COLEOPTERA	COCCINELLIDAE	COCCINELLA	SEPTEMPUNCTATA BRUCKII	10
LEPIDOPTERA	NOCTUIDAE	HADENA	SERENA	5
LEPIDOPTERA	GEOMETRIDAE	PTYCHOPODA	SERIATA	12 16
LEPIDOPTERA	GEOMETRIDAE	STERRHA	SERIATA	(SEE PTYCHOPODA SERIATA)
DIPTERA	TACHINIDAE	UGYMYIA	SERICARIAE	12
LEPIDOPTERA	CRYPTOPHASIDAE	NEPHANTIS	SERINOPA	(SEE OPISINA ARENOSELLA)
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	SERTIFER	12 16 17
HYMENOPTERA	DIPRIONIDAE	TENTHREDO	SERTIFERA	(SEE NEODIPRION SERTIFER)
LEPIDOPTERA	GEOMETRIDAE	SEMIOTHISA	SEXMACULATA	9
LEPIDOPTERA	SPHINGIDAE	MANDUCA	SEXTA	5 9 12 17
LEPIDOPTERA	SPHINGIDAE	PROTOPARCE	SEXTA	(SEE MANDUCA SEXTA)
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	SIBIRICUS	9
ORTHOPTERA	ACRIDIDAE	GOMPHOCERUS	SIBIRICUS	19
DIPTERA	CULICIDAE	AEDES	SIERRENSIS	5 10
LEPIDOPTERA	NOCTUIDAE	PLUSIA	SIGNATA	12
LEPIDOPTERA	HEPIALIDAE	WISEANA	SIGNATA	12 19
DIPTERA	CULICIDAE	ORTHOPODOMYIA	SIGNIFERA	5 17
COLEOPTERA	SCARABAEIDAE	GEOTRUPES	SILVATICUS	19
HYMENOPTERA	DIPRIONIDAE	DIPRION	SIMILIS	12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	SIMILIS	5 10 12
LEPIDOPTERA	LYMANTRIIDAE	PORTHESIA	SIMILIS	(SEE EUPROCTIS SIMILIS)
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	SIMILIS XANTHOCAMPA	12
LEPIDOPTERA	GEOMETRIDAE	PERIBATODES	SIMPLICIARIA	12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	SIMULANS	3 13
LEPIDOPTERA	SCYTHRIDIDAE	SCYTHRIS	SINENSIS	10
LEPIDOPTERA	LIMACODIDAE	THOSEA	SINENSIS	9 12
LEPIDOPTERA	LIMACODIDAE	PARASA	SINICA	9 12
LEPIDOPTERA	ZYGAEINIDAE	PRYERIA	SINICA	10
LEPIDOPTERA	NOTODONTIDAE	LEPTONATADA	SJOSTEDTII	17
DIPTERA	CULICIDAE	WYEMYIA	SMITHII	12
LEPIDOPTERA	NOCTUIDAE	BLEPHARITA	SOLIERI	5
LEPIDOPTERA	NOCTUIDAE	CRINO	SOLIERI	(SEE BLEPHARITA SOLIERI)
DIPTERA	CULICIDAE	AEDES	SOLLICITANS	5 10 12
COLEOPTERA	SCARABAEIDAE	AMPHIMALLON	SOLSTITIALIS	19
HYMENOPTERA	ICHNEUMONIDAE	CAMPOLETIS	SONORENSIS	13 17
DIPTERA	TACHINIDAE	EXORISTA	SORBILLANS	10



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	NOCTUIDAE	APAMEA	SORDENS	9
LEPIDOPTERA	NOCTUIDAE	HADENA	SORDIDA	9 12
LEPIDOPTERA	NOCTUIDAE	AGROTIS	SP.	17
LEPIDOPTERA	ARCTIIDAE	AMSACTA	SP.	12
HEMIPTERA	APHIDIDAE	APHIS	SP.	17
DIPTERA	CALLIPHORIDAE	CALLIPHORA	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	CAMPOPLEX	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	CASINARIA	SP.	13
DIPTERA	CERATOPOGONIDAE	CULICOIDES	SP.	5 10
COLEOPTERA	SCARABAEIDAE	DASYGNATHUS	SP.	19
HYMENOPTERA	ICHNEUMONIDAE	DEVORGILLA	SP.	(SEE VENTURIA SP.)
HYMENOPTERA	ICHNEUMONIDAE	DIADAGMA	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	ERIBORUS	SP.	13
LEPIDOPTERA	NOCTUIDAE	EUPSILIA	SP.	12
HYMENOPTERA	ICHNEUMONIDAE	GLYPTA	SP.	13
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	SP.	12
COLEOPTERA	SCARABAEIDAE	HOPLIA	SP.	19
HYMENOPTERA	ICHNEUMONIDAE	HOROGENES	SP.	(SEE DIADAGMA SP.)
LEPIDOPTERA	SATURNIIDAE	HYLESIA	SP.	12
HYMENOPTERA	ICHNEUMONIDAE	HYPOSOTER	SP.	13
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	SP.	9
LEPIDOPTERA	LIMACODIDAE	NATADA	SP.	17
HYMENOPTERA	ICHNEUMONIDAE	NEMERITIS	SP.	(SEE VENTURIA SP.)
TRICHOPTERA	LIMNephilidae	NEOPHYLAX	SP.	12
LEPIDOPTERA	GEOMETRIDAE	NYCTOBIA	SP.	16
COLEOPTERA	SCARABAEIDAE	ODONTIRIA	SP.	10
COLEOPTERA	SCARABAEIDAE	OPOGONIA	SP.	10
LEPIDOPTERA	LASIOCAMPIDAE	PACHYMETANA	SP.	13
LEPIDOPTERA	NOCTUIDAE	PERIDROMA	SP.	9 12
DIPTERA	CALLIPHORIDAE	PHORMIA	SP.	13
ORTHOPTERA	GRYLLIDAE	PTERONEMOBIUS	SP.	13
LEPIDOPTERA	GEOMETRIDAE	SCOPULA	SP.	10
LEPIDOPTERA	LIMACODIDAE	SIBINE	SP.	17
DIPTERA	SIMULIIDAE	SIMULIUM	SP.	10
HYMENOPTERA	FORMICIDAE	SOLENOPHIS	SP.	17
LEPIDOPTERA	NOCTUIDAE	SPODOPTERA	SP.	12
HYMENOPTERA	ICHNEUMONIDAE	TRANOSEMA	SP.	13
HYMENOPTERA	ICHNEUMONIDAE	VENTURIA	SP.	13
LEPIDOPTERA	TORTRICIDAE	ZEIRAPHERA	SP.	9
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	SPECTABILIS	5 9 12
HYMENOPTERA	SIRICIDAE	XERIS	SPECTRUM	5
LEPIDOPTERA	PYRALIDAE	DIORYCTRIA	SPLENDIDELLA	17
HYMENOPTERA	PAMPHILIIDAE	LYDA	STELLATA	(SEE ACANTHOLYDA MEMORALIS)
DIPTERA	CULICIDAE	ANOPHELES	STEPHENSII	3 5 13
COLEOPTERA	SCARABAEIDAE	GEOTRUPES	STERCOROSUS	19
LEPIDOPTERA	PYRALIDAE	LOXOSTEGE	STICTICALIS	9 12
DIPTERA	CULICIDAE	AEDES	STICTICUS	5 10
NEUROPTERA	HEMEROBIIIDAE	HEMEROBIUS	STIGMA	5 12
DIPTERA	CULICIDAE	AEDES	STIMULANS	10
DIPTERA	CULICIDAE	AEDES	STRAMINEUS	10
LEPIDOPTERA	GEOMETRIDAE	BISTON	STRATARIA	12
LEPIDOPTERA	GEOMETRIDAE	CYSTIDIA	STRATONICE STRATONICE	10
HEMIPTERA	DELPHACIDAE	LAODELPHAX	STRIATELLA	10
LEPIDOPTERA	NOCTUIDAE	MAMESTRA	SUASA	12
LEPIDOPTERA	GEOMETRIDAE	SELIDOSEMA	SUAVIS	5 12
LEPIDOPTERA	ARCTIIDAE	SPILARCTIA	SUBCARNEA	5 12
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	SUBFLAVA	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	SUBFLEXA	12
COLEOPTERA	LUCANIDAE	FIGULUS	SUBLAEVIS	19
DIPTERA	CULICIDAE	ANOPHELES	SUBPICTUS	17
LEPIDOPTERA	GEOMETRIDAE	SCOPULA	SUBPUNCTARIA	12
LEPIDOPTERA	GELECHIIDAE	STOMOPTERYX	SUBSESCIVELLA	(SEE APROAEREMA MODICELLA)
LEPIDOPTERA	GEOMETRIDAE	ENOMOS	SUBSIGNARIUS	12
LEPIDOPTERA	NOCTUIDAE	FELTIA	SUBTERRANEA	9
LEPIDOPTERA	GEOMETRIDAE	HESPERUMIA	SULPHURARIA	12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	SUPERANS	5

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	PYRALIDAE	CHILO	SUPPRESSALIS	9 10 12
LEPIDOPTERA	GEOMETRIDAE	BUZURA	SUPPRESSARIA	12
COLEOPTERA	BEUPRESTIDAE	AGRILUS	SUVOROVII POPULNEUS	5
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	SWAINEI	12
DIPTERA	COELOPIDAE	CHAETOCOELOPA	SYDNEYENSIS	13
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	TABULAEFORMIS	5
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	TAEDAE LINEARIS	12
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	TAEDAE TAEDAE	12 16
DIPTERA	CULICIDAE	AEDES	TAENIORHYNCHUS	5 10 12 13
LEPIDOPTERA	NYMPHALIDAE	VANESSA	TAMMEAMEA	16
HYMENOPTERA	SIRICIDAE	UROCERUS	TARDIGRADUS	5
DIPTERA	CULICIDAE	CULEX	TARSALIS	5 13 17
ACARI	ARGASIDAE	ORNITHODOROS	TARTAKOVSKYI	17
COLEOPTERA	SCARABAEIDAE	APHODIUS	TASMANIAE	13 19
DIPTERA	DROSOPHILIDAE	DROSOPHILA	TEISSIERI	13
ACARI	TETRANYCHIDAE	TETRANYCHUS	TELARIUS	(SEE TETRANYCHUS URTICAE)
LEPIDOPTERA	GEOMETRIDAE	PHTHONOSEMA	TENDINOSARIA	12
DIPTERA	CHIRONOMIDAE	CAMPTOCHIRONOMUS	TENTANS	(SEE CHIRONOMUS TENTANS)
DIPTERA	CHIRONOMIDAE	CHIRONOMUS	TENTANS	12 17 19
HYMENOPTERA	ICHNEUMONIDAE	MESOLEIUS	TENTHREDINIS	13
LEPIDOPTERA	LYMANTRIIDAE	EUPROCTIS	TERMINALIS	16
ORTHOPTERA	ACRIDIDAE	CHORTOICETES	TERMINIFERA	13
HYMENOPTERA	APIIDAE	BOMBUS	TERRESTRIS	1
LEPIDOPTERA	NOCTUIDAE	PRODENIA	TERRICOLA	12
DIPTERA	CULICIDAE	CULEX	TERRITANS	5 10 17
LEPIDOPTERA	PYRALIDAE	MARUCA	TESTULALIS	5
HYMENOPTERA	BRACONIDAE	CHELONUS	TEXANUS	13 17
DIPTERA	CULICIDAE	AEDES	THIBAUTI	5
LEPIDOPTERA	GEOMETRIDAE	BUZURA	THIBTARIA	12
ACARI	ARGASIDAE	ORNITHODOROS	THOLOZANI	17
LEPIDOPTERA	LYONETIIDAE	BUCCULATRIX	THURBERIELLA	12
LEPIDOPTERA	SPHINGIDAE	DILINA	TILIAE	5
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	TILIARIA	5 12
LEPIDOPTERA	GEOMETRIDAE	MYRTETA	TINAGMARIA	12
LEPIDOPTERA	GEOMETRIDAE	PHIGALIA	TITEA	12
LEPIDOPTERA	NOCTUIDAE	AGROTIS	TOKIONIS	9
DIPTERA	DROSOPHILIDAE	DROSOPHILA	TOLTECA	3
DIPTERA	CULICIDAE	AEDES	TORMENTOR	12
LEPIDOPTERA	PYRALIDAE	AMYELOIS	TRANSITELLA	12 13 17
LEPIDOPTERA	PYRALIDAE	PARAMYELOIS	TRANSITELLA	(SEE AMYELOIS TRANSITELLA)
LEPIDOPTERA	SATURNIIDAE	HEMILEUCA	TRICOLOR	12 16
LEPIDOPTERA	NOCTUIDAE	DISCESTRA	TRIFOLII	(SEE SCOTOGRAMMA TRIFOLII)
LEPIDOPTERA	LASIOCAMPIDAE	LASIOCAMPA	TRIFOLII	12
LEPIDOPTERA	NOCTUIDAE	SCOTOGRAMMA	TRIFOLII	5 9 12
COLEOPTERA	CHRYSOMELIDAE	CEROTOMA	TRIFURCATA	17
LEPIDOPTERA	LIMACODIDAE	DARNA	TRIMA	9 13
DIPTERA	CULICIDAE	AEDES	TRISERIATUS	5 12 13 17
DIPTERA	CECIDOMYIIDAE	CONTARINIA	TRITICI	16
COLEOPTERA	SCARABAEIDAE	PERICOPTUS	TRUNCATUS	13
DIPTERA	TEPHRITIDAE	DACUS	TRYONI	14
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	TSUGAE	12
DIPTERA	DROSOPHILIDAE	ZAPRIONUS	TUBERCULATUS	13
DIPTERA	SIMULIIDAE	SIMULIUM	TUBEROSUM	5
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	TURBATA	12
ORTHOPTERA	ACRIDIDAE	ACRIDA	TURRITA	10
LEPIDOPTERA	NOCTUIDAE	ADRIS	TYRANNUS AMURENSIS	5
ACARI	TETRANYCHIDAE	PANONYCHUS	ULMI	13 17
LEPIDOPTERA	HEPIALIDAE	WISEANA	UMBRACULATA	9 12 19
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGMA	UNDANS	5 12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	UNDANS	(SEE CYCLOPHRAGMA UNDANS)
LEPIDOPTERA	LASIOCAMPIDAE	METANASTRIA	UNDANS	(SEE CYCLOPHRAGMA UNDANS)
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGMA	UNDANS FASCIATELLA	12
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGMA	UNDANS FLAVEOLA	12
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	UNDANS FLAVEOLA	(SEE CYCLOPHRAGMA UNDANS FLAVEOLA)
LEPIDOPTERA	NOCTUIDAE	MOCIS	UNDATA	5
COLEOPTERA	CHRYSOMELIDAE	DIABROTICA	UNDECIMPUNCTATA	13 17

ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	LASIOCAMPIDAE	BHIMA	UNDULOSA	12
LEPIDOPTERA	NOCTUIDAE	MYTHMNA	UNIPUNCTA	(SEE PSEUDALETIA UNIPUNCTA)
LEPIDOPTERA	NOCTUIDAE	PSEUDALETIA	UNIPUNCTA	5 9 10 12 13 16
LEPIDOPTERA	NYMPHALIDAE	AGLAIS	URTICAE	5 6 12 16
ACARI	TETRANYCHIDAE	TETRANYCHUS	URTICAE	17
LEPIDOPTERA	NYMPHALIDAE	VANESSA	URTICAE	(SEE AGLAIS URTICAE)
ORTHOPTERA	ACRIDIDAE	SCHISTOCERCA	VAGA	4
LEPIDOPTERA	GEOMETRIDAE	ERANNIS	VANCOUVERENSIS	12
LEPIDOPTERA	NYMPHALIDAE	AGRAULIS	VANILLAE	6 12 13
LEPIDOPTERA	ANTHELIDAE	ANTHELA	VARIA	12
LEPIDOPTERA	TORTRICIDAE	ACLERIS	VARIANA	9 12
LEPIDOPTERA	BOMBYCIDAE	OCINARA	VARIANS	12
LEPIDOPTERA	PSYCHIDAE	CRYPTOTHELEA	VARIEGATA	12
LEPIDOPTERA	PSYCHIDAE	EUMETA	VARIEGATA	(SEE CRYPTOTHELEA VARIEGATA)
DIPTERA	CULICIDAE	PSOROPHORA	VARIPES	10 12
COLEOPTERA	COCCINELLIDAE	EPILACHNA	VARIVESTIS	17
LEPIDOPTERA	TORTRICIDAE	ARGYROTAENIA	VELUTINANA	9
DIPTERA	CHAOBORIDAE	MOCHLONYX	VELUTINUS	10
LEPIDOPTERA	GEOMETRIDAE	ENYPIA	VENATA	12
LEPIDOPTERA	LIMACODIDAE	SCOPELODES	VENOSA	12
DIPTERA	SIMULIIDAE	SIMULIUM	VENUSTUM	5
LEPIDOPTERA	HELICONIIDAE	MECHANITIS	VERITABILIS	17
LEPIDOPTERA	GEOMETRIDAE	PALEACRITA	VERNATA	5 12
LEPIDOPTERA	GEOMETRIDAE	PHALAEA	VERNATA	(SEE PALEACRITA VERNATA)
COLEOPTERA	SCARABAEIDAE	RHOPAEA	VERRAUXI	19
ACARI	ARGASIDAE	ORNITHODOROS	VERRUCOSUS	17
LEPIDOPTERA	SPHINGIDAE	CELERIO	VESPERTILIO	16
LEPIDOPTERA	LYMANTRIIDAE	ORGYIA	VETUSTA	12
DIPTERA	CULICIDAE	AEDES	VEXANS	6 10
COLEOPTERA	CHRYSOMELIDAE	CHRYSOMELA	VIGINTIPUNCTATA	10
COLEOPTERA	CHRYSOMELIDAE	MICRODERA	VIGINTIPUNCTATA	(SEE CHRYSOMELA VIGINTIPUNCTATA)
LEPIDOPTERA	ARCTIIDAE	ARCTIA	VILLICA	5 12
COLEOPTERA	SCARABAEIDAE	ANOXIA	VILLOSA	19
HYMENOPTERA	TENTHREDINIDAE	CLADIUS	VIMINALIS	(SEE TRICHIOCAMPUS VIMINALIS)
HYMENOPTERA	TENTHREDINIDAE	TRICHIOCAMPUS	VIMINALIS	12
LEPIDOPTERA	GEOMETRIDAE	OENOCROMA	VINARIA	13
LEPIDOPTERA	NOTODONTIDAE	CERURA	VINULA	5
HYMENOPTERA	XYLOCOPIIDAE	XYLOCOPA	VIOLACEA	15
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	VIOLASWINHOL	12
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	VIRESCENS	5 12 13 16
DIPTERA	SIMULIIDAE	SIMULIUM	VIRGATUM	10
HYMENOPTERA	DIPRIONIDAE	NEODIPRION	VIRGINIANA	12
LEPIDOPTERA	ARCTIIDAE	DIACRISIA	VIRGINICA	5 9 12
LEPIDOPTERA	PIERIDAE	ARTOGEIA	VIRGINIENSIS	(SEE PIERIS VIRGINIENSIS)
LEPIDOPTERA	PIERIDAE	PIERIS	VIRGINIENSIS	9
LEPIDOPTERA	ARCTIIDAE	APANTESIS	VIRGO	16
LEPIDOPTERA	TORTRICIDAE	TORTRIX	VIRIDANA	5 12 16
LEPIDOPTERA	TORTRICIDAE	CHORISTONEURA	VIRIDIS	9
LEPIDOPTERA	LIMACODIDAE	LATOIA	VIRIDISSIMA	6
DIPTERA	DROSOPHILIDAE	DROSOPHILA	VIRILIS	13 17
LEPIDOPTERA	LASIOCAMPIDAE	TRABALA	VISHNOU	12
DIPTERA	SIMULIIDAE	SIMULIUM	VITTATUM	5 6
DIPTERA	CALLIPHORIDAE	CALLIPHORA	VOMITORIA	10 12 16
HYMENOPTERA	VESPIDAE	VESPULA	VULGARIS	15
LEPIDOPTERA	NOCTUIDAE	BELLURA	VULNIFICA	(SEE BELLURA GORTYNOIDES)
LEPIDOPTERA	NOCTUIDAE	DIPAROPSIS	WATERSI	5 12
LEPIDOPTERA	THAUMETOPOEIDAE	THAUMETOPOEA	WILKINSONI	5 12
DIPTERA	DROSOPHILIDAE	DROSOPHILA	WILLISTONI	3 13 17
LEPIDOPTERA	LYMANTRIIDAE	PORTHESIA	XANTHOCAMPA	5
LEPIDOPTERA	NOCTUIDAE	ANTITYPE	XANTHOMISTA	5
LEPIDOPTERA	HEPIALIDAE	METAHEPIALUS	XENOCTENIS	13
LEPIDOPTERA	PAPILIONIDAE	PAPILIO	XUTHUS	12
LEPIDOPTERA	LYMANTRIIDAE	LYMANTRIA	XYLINA	12
LEPIDOPTERA	PLUTELLIDAE	PLUTELLA	XYLOSTELLA	9 10 12 13
DIPTERA	DROSOPHILIDAE	DROSOPHILA	YAKUBA	13
LEPIDOPTERA	LASIOCAMPIDAE	CYCLOPHRAGNA	YAMADAI	5 12



ORDER	FAMILY	GENUS	SPECIES	DISEASES
LEPIDOPTERA	LASIOCAMPIDAE	DENDROLIMUS	YAMADAI	(SEE CYCLOPHRAGMA YAMADAI)
LEPIDOPTERA	LASIOCAMPIDAE	KUNUGIA	YAMADAI	(SEE CYCLOPHRAGMA YAMADAI)
LEPIDOPTERA	SATURNIIDAE	ANTHERAEA	YAMAMAI	10 12 16
LEPIDOPTERA	NOCTUIDAE	AGROTIS	YPSILON	(SEE AGROTIS IPSILON)
LEPIDOPTERA	NOCTUIDAE	HELIOTHIS	ZEALANDICA	5 9 10 12 13
COLEOPTERA	SCARABAEIDAE	COSTELYTRA	ZEALANDICA	10 13
LEPIDOPTERA	PYRALIDAE	ACROBASIS	ZELLERI	19



**Key to Diseases and  
Disease Groups****Code     Diseases**

- |    |  |
|----|--|
| 1  | Bee acute paralysis  |
| 2  | Bee chronic paralysis  |
| 3  | CO <sub>2</sub> sensitivity                                    |
| 4  | Crystalline-array virosis                                      |
| 5  | Cytoplasmic polyhedrosis                                       |
| 6  | Densonucleosis   |
| 7  | Flacherie, excluding Gattine                                   |
| 8  | Gattine  |
| 9  | Granulosis   |
| 10 | Iridescent virosis   |
| 11 | Malaya disease   |
| 12 | Nuclear polyhedrosis   |
| 13 | Other nonoccluded-virus diseases                               |
| 14 | Other occluded-virus diseases                                  |
| 15 | Paralysis, other than bee acute and bee chronic paralyse       |
| 16 | Polyhedrosis, not further identified as cytoplasmic or nuclear |
| 17 | Presumed virosis   |
| 18 | Sacbrood   |
| 19 | Spheroidosis, insect pox                                       |
| 20 | Watery disintegration  |
| 21 | Hairless-black syndrome  |
| 22 | Filamentous-virus disease                                      |







**Martignoni, Mauro E.; Iwai, Paul J.** A catalog of viral diseases of insects, mites, and ticks. 4th ed. Gen. Tech. Rep. PNW-195. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station; **1986.** 51 p.

This comprehensive catalog of viral diseases of three large groups of arthropods updates the previous surveys of the world's literature published by Hughes in 1957, by Martignoni and Langston in 1960, and by Martignoni and Iwai in 1975. This computer-based catalog lists over 1,100 species of insects, mites, and ticks, each reported to have one or more of 22 viral diseases or disease groups, for a total of about 1,690 host-virus records. The catalog consists of two lists. In the first one, the hosts are listed in taxonomic sequence (order, family, genus, species). Families appear alphabetically within each order, genera alphabetically within each family, and species alphabetically within each genus. In the second, all hosts are listed alphabetically by specific names. The host-virus records are stored on computer tape and disks.

**Keywords:** Virus (-insecta, mites, virus catalog (computerized), insect damage control (forest), diseases (insect).

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